SPACE RESEARCH IN INDIA

JANUARY 2018 - JUNE 2020

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START

SPACE RESEARCH IN INDIA

January 2018 – June 2020

A Report of the

Indian National Committee for Space Research (INCOSPAR)

Indian National Science Academy (INSA)

Indian Space Research Organization (ISRO)

For the

43rd COSPAR Scientific Assembly

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Sydney, Australia

INDIAN SPACE RESEARCH ORGANISATION
BENGALURU

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Cover Page Images:

Upper: *Colour composite picture of face-on spiral galaxy M 74 - from UVIT onboard AstroSat. Here blue colour represent image in far ultraviolet and green colour represent image in near ultraviolet.The spiral arms show the young stars that are copious emitters of ultraviolet light.*

Lower: *Sarabhai crater as imaged by Terrain Mapping Camera-2 (TMC-2)onboard Chandrayaan-2 Orbiter.TMC-2 provides images (0.4µm to 0.85µm) at 5m spatial resolution*

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FOREWORD

Space Science research has always been a very important area of focus for ISRO. India has an expanding program in using space as a platform for research. ISRO had a few dedicated science missions in recent decades aimed at studying the Moon, and the Mars and also for astronomical observations. ISRO's Space Science program has reached new heights with the first mission to the Moon, Chandrayaan-1 in 2008 and launch of AstroSat, India's first multi-wavelength astronomy satellite, in 2015. These missions made very important science contributions to solar system research and in understanding interaction processes in the wider cosmos.

The 2018-2020 timeframe includes the successful placement of Chandrayaan-2 orbiter mission around Moon. With eight payloads onboard, Chandrayaan-2 is poised to make very important results addressing the distribution of water-ice on the surface globally and sub-surface presence at the poles using very sophisticated IR spectrometers and dual frequency Synthetic Aperture radar experiments.

This period also yielded very important research results by institutions and universities in India. Many important astrophysics results from the AstroSat mission are summarised in this report. It reflects the expanding research program at individual institutions and also shows an increasing involvement of institutions in space science research.

The launch of Aditya-L1 and XPoSat missions are the future science missions envisaged in the next two years. Aditya-L1, a dedicated solar observatory to be positioned at Lagrange point 1 in the Sun-Earth system, is a key mission to address coronal heating, UV irradiance and in-situ particle and field measurements with linkage to space weather. After many decades, XPoSat is the first of a new set of global missions to address the renewed interest in X-ray polarisation measurement of cosmic sources.

ISRO has also enhanced its international collaborations in space science research. India shares the data from its space science satellites with the international community. The data from Chandrayaan-1 &2, Mars Orbiter Mission, Astrosat etc. are provided to the international scientific community through the Indian Space Science Data Center. A future joint mission is planned with JAXA for the exploration of the lunar south pole.

In order to pursue space science research and to provide more opportunities for the Indian research community to expand its research horizons ISRO will have more focused collaborative efforts with International agencies and Institutes towards realisation of advanced space missions and science payloads.

It is my extreme privilege and great pleasure to present the INCOSPAR report to the 43rd COSPAR Scientific Assembly, 28 Jan – 4 Feb 2021 to be held at Sydney, Australia. I sincerely hope that this information strengthens the existing cooperation and creates new ones among the global space community. I wish the 43rd COSPAR Scientific Assembly a very big success.

28/1/2021

Dated: January 28th, 2021

(कै. शिवन / **K. Sivan**)

With great pleasure I introduce the report on Space Research in India, prepared for the 43rd COSPAR Scientific Assembly, 28 January – 4 February 2021, Sydney, Australia, by the Indian National Committee for Space Research (INCOSPAR), Indian National Science Academy (INSA), and Indian Space Research Organization (ISRO). The report gives an overview of the important accomplishments, achievements and research activities conducted in India in several areas of near- Earth space, Sun, Planetary science, and Astrophysics for the duration of two and half years (Jan 2018 – June 2020). The report also reflects the major facilities for space research available in India and the important scientific results obtained using these facilities. The report summarizes the contributions from various ISRO centres, national institutes, and the universities.

The period spanning 2018–2020 witnessed noteworthy developments on many fronts along with significant growth in research and academic activities and exploration program. This period, specially the year 2020 has been challenging in almost all the strata of human life due to the pandemic situation faced world-wide. This has taught us many lessons and has shown that by working together only we can handle problems of global nature. It has also paved new ways for scientists to interact and conduct meetings and discussion forums connecting remotely.

In the area of space science, one of the major milestone during this period is the launch of Indian second Moon mission Chandrayaan-2 on 22 July 2019, and its insertion into the lunar orbit on 20 August 2019. The Chandrayaan-2 mission had three components: Orbiter, Lander and Rover. Though the soft-landing attempt near the south pole of the Moon was unsuccessful, the Orbiter placed in the 100-km polar orbit is providing high-quality observations. The early science results from observations are being published. All the eight experiments aboard Orbiter are working well, and first-set of data has been released to public on 24 December 2020. At present about 1100 worldwide users have registered for publicly available Chandrayaan-2 data. Scientific publications reporting new results from the observations made by the first lunar mission of India Chandrayaan-1 are continuing. The Indian Mars Orbiter mission continues to orbit Mars completing more than six years of operations around Mars.

Another major accomplishment in space science is the completion of 5 years of AstroSat in operation on 28 September 2020. AstroSat is India's first multi- wavelength astronomical mission. From October 2017, the observatory is open to Indian and International astronomy community. Currently AstroSat has a registered user base of around 1500 from 48 countries. Several interesting and important science outcome have emerged from AstroSat. In the first five-years AstroSat has produced more than 150 refereed publications, and more than thousand conference proceedings, GCN circulars, Astronomer's telegrams and other non-refereed publications. The discovery of Lyman continuum emission from a low mass clumpy galaxy at z = 1.42 in extreme UV by Ultraviolet Imaging Telescope (UVIT) onboard AstroSat is a breakthrough result. This opens up a new window to constrain the shape of the ionizing spectrum. The other notable results from AstroSat during last two and half years are the discovery of extended UV emission in Butterfly nebula, detection of rare triple thermo-nuclear bursts, estimation of mass of a black-hole rotating

with near to maximal possible speed, detection of X-ray polarization from Crab, resolving the nature of a SU Lyn star using spectroscopic capability of UVIT, and several gamma ray bursts, etc.

India joined the elite club of countries, which have discovered planets around stars beyond our solar system, when a sub-Saturn or super-Neptune size planet (mass of about 27 Earth Mass and size of 6 Earth Radii) known as EPIC 211945201b or K2-236b was discovered using the PARAS instrument on the 1.2-m telescope of Physical Research Laboratory at Mt. Abu.

In the last two years India has made significant contributions towards the Thirty Meter Telescope (TMT) International Observatory. India TMT has completed the state-of-the art facility for large optics fabrication for polishing of 90 mirror segments of 1.45-m diameter using stress mirror polishing (SMP) technique. Apart from hardware, India TMT continues to provide software modules as part of observatory software suite and contributing to both 1st and 2nd generation instrument development.

Towards the expansion of Indian planetary exploration program, ISRO is conducting study for a possible mission to Venus and next mission to Mars in the coming decade. An announcement of opportunity was released by ISRO for participation of international partners for the Venus mission. Indian first solar observatory Aditya-L1 is getting ready and would be launched very soon.

During the past two and half years, the Indian space community has been very active in conducting investigations in many diverse areas related to Astronomy and Astrophysics, Solar Physics, Space and Atmospheric Sciences, Planetary Sciences, Geomagnetism and Geosciences. Observations have been made using various tools and in several wavelengths. This report describes highlights of the research from the studies on ionosphere, magnetosphere, solar wind and space weather, lunar and planetary studies, oceanography, atmospheric structure and dynamics; cloud and convective system; aerosols, radiation and trace gases, weather and climate change, Sun and the solar system bodies, stars, galaxies, galactic and extragalactic astronomy and cosmology. Studies in the area of astro-chemistry have been initiated and expanded.

I would like to thank all the scientists who have sent the inputs on the space research activities being carried out in their respective Institutes and Departments in time to prepare this report. I would like to acknowledge the hard work put in by Space Science Programme Office, ISRO HQ, Bangalore for compiling and editing the report on behalf of INCOSPAR.

Anil Bhardwaj
Chairman, INCOSPAR

JOINT NATIONAL COMMITTEE FOR COMMITTEE ON SPACE RESEARCH (COSPAR); INTERNATIONAL UNION OF RADIO SCIENCE (URSI) & SCIENTIFIC COMMITTEE ON SOLAR-TERRESTRIAL PHYSICS (SCOSTEP), JANUARY 1, 2020 – DECEMBER 31, 2023

Dr. Anil Bhardwaj	Chairperson
Dr. Amit Kumar Patra	Member
Dr. S. Seetha	Member
Dr. Virupakshi Reddy	Member
Dr. P.K. Manoharan	Member
Dr. Devendraa Siingh	Member

ORGANISATION AND FACILITIES

1. ORGANISATION OF SPACE RESEARCH

• INDIAN NATIONAL COMMITTEE FOR SPACE RESEARCH (INCOSPAR)

Indian National Committee for Space Research (INCOSPAR) is one of the committees of the Indian National Science Academy (INSA), which is the national adhering organisation to the International Council of Scientific Unions (ICSU), and a member of ICSU Council. Presently, Dr. Anil Bhardwaj is the Chairman of INCOSPAR and Dr. K. Rajeev is the national representative at COSPAR Council. INCOSPAR has the following terms of reference:

i. To recommend and promote national activities and international co-operation in space exploration and space research.

ii. To provide necessary liaison with the COSPAR of ICSU, and encourage participation in international activities which contribute to the peaceful uses of outer space.

• SPACE COMMISSION, DEPARTMENT OF SPACE AND INDIAN SPACE RESEARCH ORGANISATION

The Space Commission and the Department of Space (DOS) were established by the Government of India in 1972 to promote development and application of space science and technology for identified national socio-economic objectives. The Space Commission lays down the framework of important space activities and advises the Government on major policies related to India's space programme. Dr. K. Sivan is the present Chairman of the Space Commission, Secretary to the Government of India in DOS and Chairman of the Indian Space Research Organisation (ISRO). DOS functions directly under the Prime Minister of India.

The Indian Space Programme is directed towards the goal of self-reliant use of space science and technology for national development, its main thrusts being:

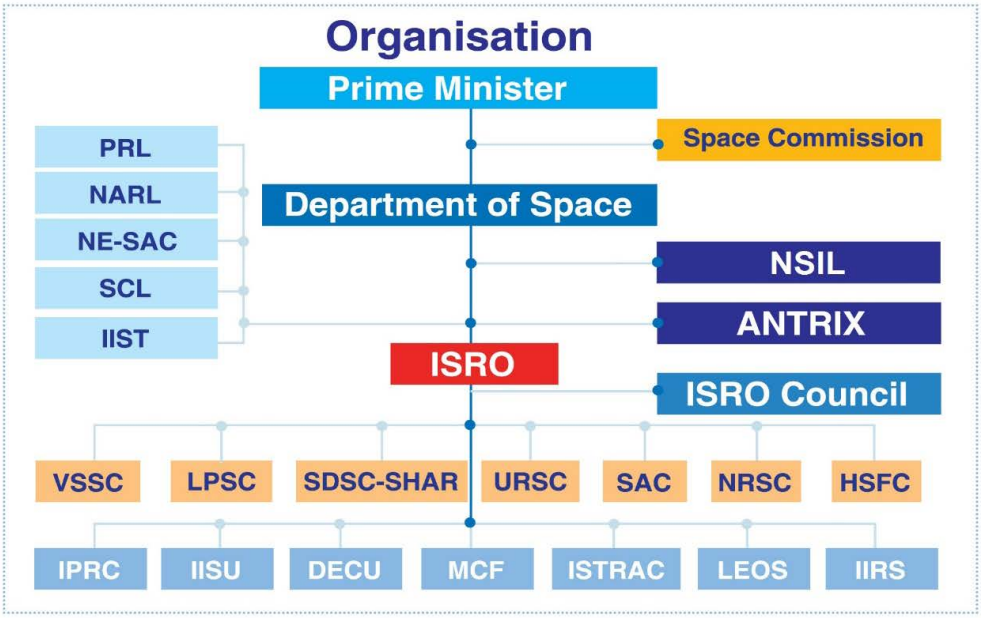
i. Satellite telecommunications, navigation, television and radio broadcasting

ii. Satellite remote sensing for resource survey and management, environmental monitoring and meteorological services.

iii. Development and operationalization of indigenous satellites and launch vehicles for providing these services.

DOS is responsible for carrying out space research and related activities in the country through ISRO's constituent units and major autonomous institutions. DOS is also the nodal department for implementation of the on-going National Natural Resources Management System (NNRMS).

The Organisation chart for Department of Space, ISRO and its major establishments are shown in Fig.1



PRL: Physical Research Laboratory **NARL:** National Atmospheric Research Laboratory **NE-SAC:** North Eastern Space Applications Centre **SCL:** Semi-Conductor laboratory **IIST:** Indian Institute of Space Science and Technology **ISRO:** Indian Space Research Organisation **Antrix:** Antrix Corporation Limited **VSSC:** Vikram Sarabhai Space Centre **LPSC:** Liquid Propulsion Systems Centre **SDSC:** Satish Dhawan Space Centre **URSC:** U R Rao Satellite Centre **SAC:** Space Applications Centrte **NRSC:** National Remote Sensing Centre **HSFC:** Human Space Flight Centre **IPRC:** ISRO Propulsion Complex **IISU:** ISRO Inertial Systems Unit **DECU:** Development and Educational Communication Unit **MCF:** Master Control Facility **ISTRAC:** ISRO Telemetry, Tracking and Command Network **LEOS:** Laboratory for Electro-Optics Systems **IIRS:** Indian Institute of Remote Sensing **NSIL:** NewSpace India Limited

Fig 1: *Organisation chart of DOS/ISRO*

2. MAJOR ACHIEVEMENTS OF THE ORGANISATION:

The stellar achievements of ISRO/DOS during the period of this report (Jan 2018-June 2020) in Launch Vehicle/Satellite Programmes and Space Science Programmes are:

ACHIEVEMENTS IN LAUNCH VEHICLE AND SATELLITE PROGRAMMES

A total of 13 launch vehicles have been flown in the duration Jan 2018-June 2020. These include nine Polar Satellite Launch Vehicles (PSLV), four Geostationary Launch Vehicles (GSLV) out which two are GSLV MkIII. These launch vehicles have placed various Indian and foreign satellites into various intended orbits. The briefs of the Indian satellites placed in the above mentioned durations are provided below:

Communication Satellites

A total of six communication satellites were launched. The satellites GSAT-6A & GSAT-7A were launched from Satish Dhawan Space Centre, Sriharikota (SDSC SHAR) on 29.03.2018 & 19.12.2018 by GSLV F-08 & F11 respectively. The satellites provide communication services in C, S & Ku band over Indian region. The satellite GSAT-29 was launched from SDSC SHAR on 14.11.2018 by GSLV MK-3 D2. It is a high-throughput communication (Ku & Ka) satellite providing high-speed bandwidth to Village Resource Centres (VRC) in rural areas. It is the heaviest satellite, weighing 3,423 kg that was placed in orbit by an Indian launch vehicle.

The satellites GSAT-11, GSAT-31 & GSAT-30 were launched from Kourou on 04.12.2018, 06.02.2019 & 17.01.2020. GSAT-11 is the first 6 tonne satellite built by ISRO providing high data rate connectivity. GSAT-30 & 31 provide communication services in Ku band over Indian region.

Earth Observation Missions

A total of six Earth observation missions were launched from SDSC SHAR. Cartosat-2F, Hysis, EMISAT, RISAT-2B, Cartosat-3 & RISAT-2BR1 were launched on 12.01.2018, 29.11.2018, 01.04.2019, 22.05.2019, 27.11.2019 & 11.12.2019 respectively in PSLV missions. These satellites provide panchromatic & multi spectral images for remote sensing applications.

Navigation Mission

IRNSS-1I the eighth satellite of the Indian Region Navigational Satellite System series was launched on 11.04.2018 by PSLV C41. The satellite provides navigation services in L5 & S bands.

Technology Demonstration Missions:

Chandrayaan-2 Lander / Rover

Chandrayaan-2 was the first Lunar Lander mission of ISRO. Chandrayaan-2 was launched on 22.07.2019 by GSLV MK-3 M1 from SDSC SHAR. It is a highly complex mission, which represents a significant technological leap compared to the previous missions of ISRO. It comprised an Orbiter, Lander and Rover to explore the unexplored South Pole of the Moon.

Microsat-1 & Microsat-1R weighing 100kg was launched on 12.01.2018 & 24.01.2019 by PSLV. These were technology demonstrator missions and the fore runner for future satellites of this series. The satellite bus is modular in design and can be fabricated and tested independently of payload.

ACHIEVEMENTS IN SPACE SCIENCE PROGRAMMES

- **MARS ORBITER MISSION (MOM)**

Mars Orbiter Mission, the maiden interplanetary mission of ISRO, launched on November 5, 2013 by PSLV-C25 got inserted into Martian orbit on September 24, 2014 in its first attempt by travelling 324 days. MOM completed six years in Martian orbit as on 24th Sep, 2020 well beyond its designed mission life of six months.

The Mars Colour Camera, one of the scientific payloads onboard MOM, has produced more than 1100 images so far. Using early MCC, images a Mars Atlas was prepared and made available on ISRO website. MOM data are made available at ISSDC website (https://mrbowse.issdc.gov.in/MOMLTA) to registered users.

Scientific analysis of the data being received from the Mars Orbiter spacecraft is in progress. About thirty scientific papers have been published so far in peer reviewed journals.

- **ASTROSAT MISSION**

AstroSat, India's first mission dedicated for astronomy completed its designed life of five years in September, 2020. AstroSat has a unique capability of simultaneous observations in a broad band from UV to hard X-rays.

AstroSat is operated as a proposal based observatory. The data from AstroSat under Announcement of Opportunity (AO) is released for public after one year of proprietory period. Currently AstroSat has a registered user base of 1483 users from 48 countries.

AstroSat data has produced about 150 refereed publications and more than thousand conference proceedings, GCN circulars, Astronomer's telegrams and other non-refereed publications.

Some of the major results from AstroSat in the last two and half years are,

1. Detection of Lyman continuum emission from z=1.42 galaxy.
2. Detection of rare triple thermo-nuclear bursts.
3. Estimation of mass of a black-hole rotating with near to maximal possible speed.
4. Discovery of extended UV emission in Butterfly nebula.
5. Detection of X-ray polarization from Crab pulsar and several GRBs (gamma ray bursts).

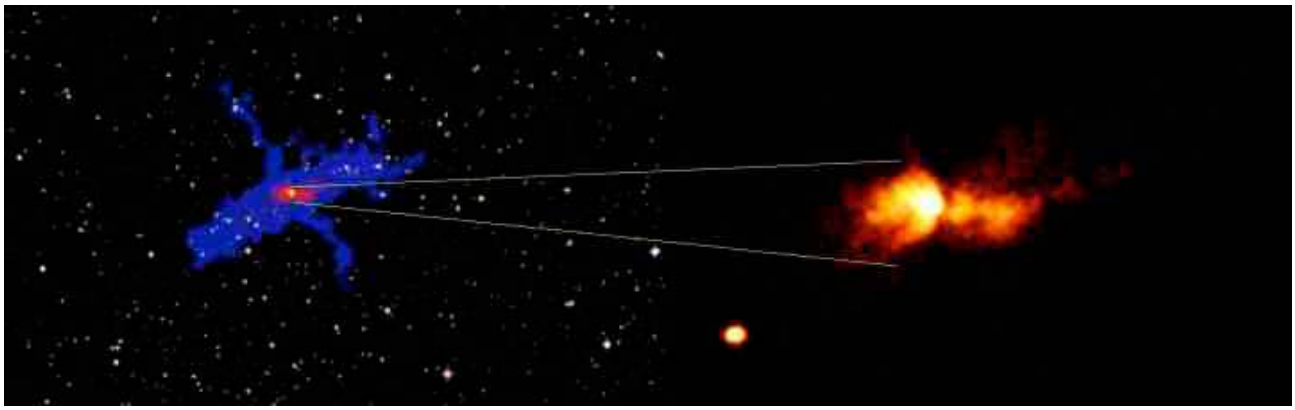


Fig 2: *AstroSat observation of NGC 6302 or Butterfly nebula showing the extended FUV emission (blue colour, left panel) as compared to the emission in optical (right panel).*

NGC 6302 is a planetary nebula popularly known as Butterfly nebula. The butterfly nebula was imaged by AstroSat's Ultra-Violet Imaging Telescope (UVIT) and was discovered that the gas which is bright in the FUV (blue color in the left image) extends beyond known wings of butterfly nebula, nearly three times of what is seen in optical (right panel).

Thermo-nuclear bursts are the eruptions that are typically observed in neutron star low mass X-ray binaries (LMXB). The burst are triggered in the neutron star envelops due to unstable nuclear burning of accreted matter from a companion. It is believed that during such a burst, all the accreted matter is burnt out. Hence it is rare to observe multiple bursts in a short scale as sufficient matter needs to be accreted on the neutron star before a new burst can ignite. One such very rare triple burst with a shortest wait time between successive bursts was observed in an LMXB 4U 1635-56.

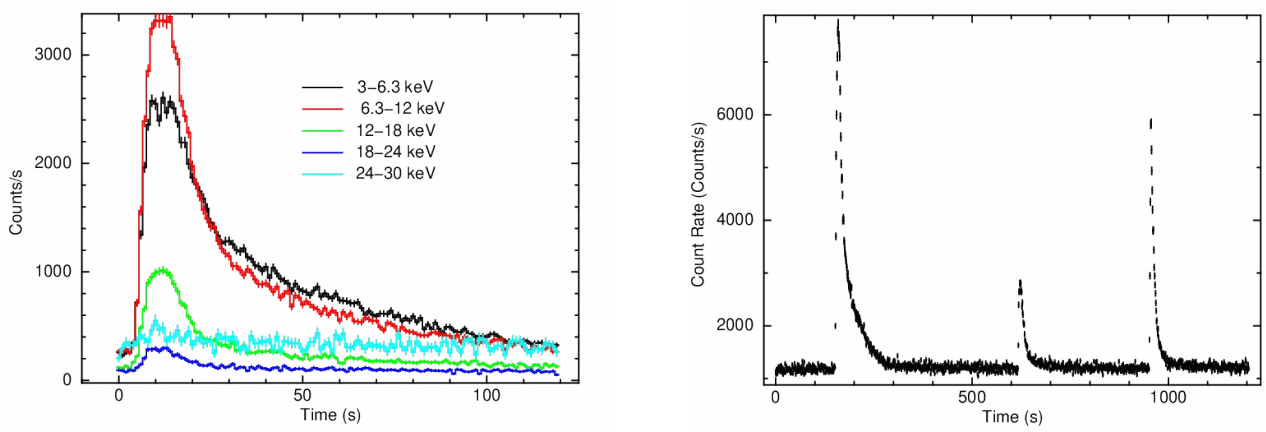


Fig 3: *LAXPC light curve of triplet bursts observed in 4U 1635-56 (right). The energy dependence of the burst is shown in the left panel.*

• INDIAN LUNAR PROGRAM

Major milestone in Indian Space Science and Planetary Exploration during this timeframe is the launch of Chandrayaan-2 mission on 22nd July 2019 and insertion into the lunar orbit on 20th August 2019. The spacecraft had three components: Orbiter, Lander and Rover. Though the soft-landing attempt of lander/ rover was not successful, the orbiter was successfully placed in the 100 km lunar orbit.

The major scientific goals are to expand the lunar scientific knowledge through detailed study of topography, mineralogy, surface chemical composition and tenuous lunar atmosphere leading to a better understanding of origin and evolution of the Moon. The orbiter completed one year around the Moon and all the eight payloads are operational. The unique payload capabilities are highest-resolution images from lunar orbital platform, first time L-band SAR operation, high spatial resolution global elemental maps, extended IR region, particle enhancement study in the geotail etc.

First year observations demonstrated its ability to contribute significantly to lunar science. Initial analysis and results from the payloads are available in the ISRO website (Visit: https://www.isro.gov.in/chandrayaan-2-completes-year-around-moon). Sarabhai crater imaged by Terrain Mapping Camera-2 was released during the Valedictory function of Vikram Sarabhai Centenary

program. The science results from payloads data are being published. With open data release on Dec 24, 2020, the total registered users at present for publicly available Chandrayaan-2 data are about 1100 worldwide.

Chandrayaan-3 activities are progressing well towards a launch in 2021. It has a lander and rover carrying same set of payloads as Chandrayaan-2. It will demonstrate landing and roving in the southern high latitudes on the lunar surface

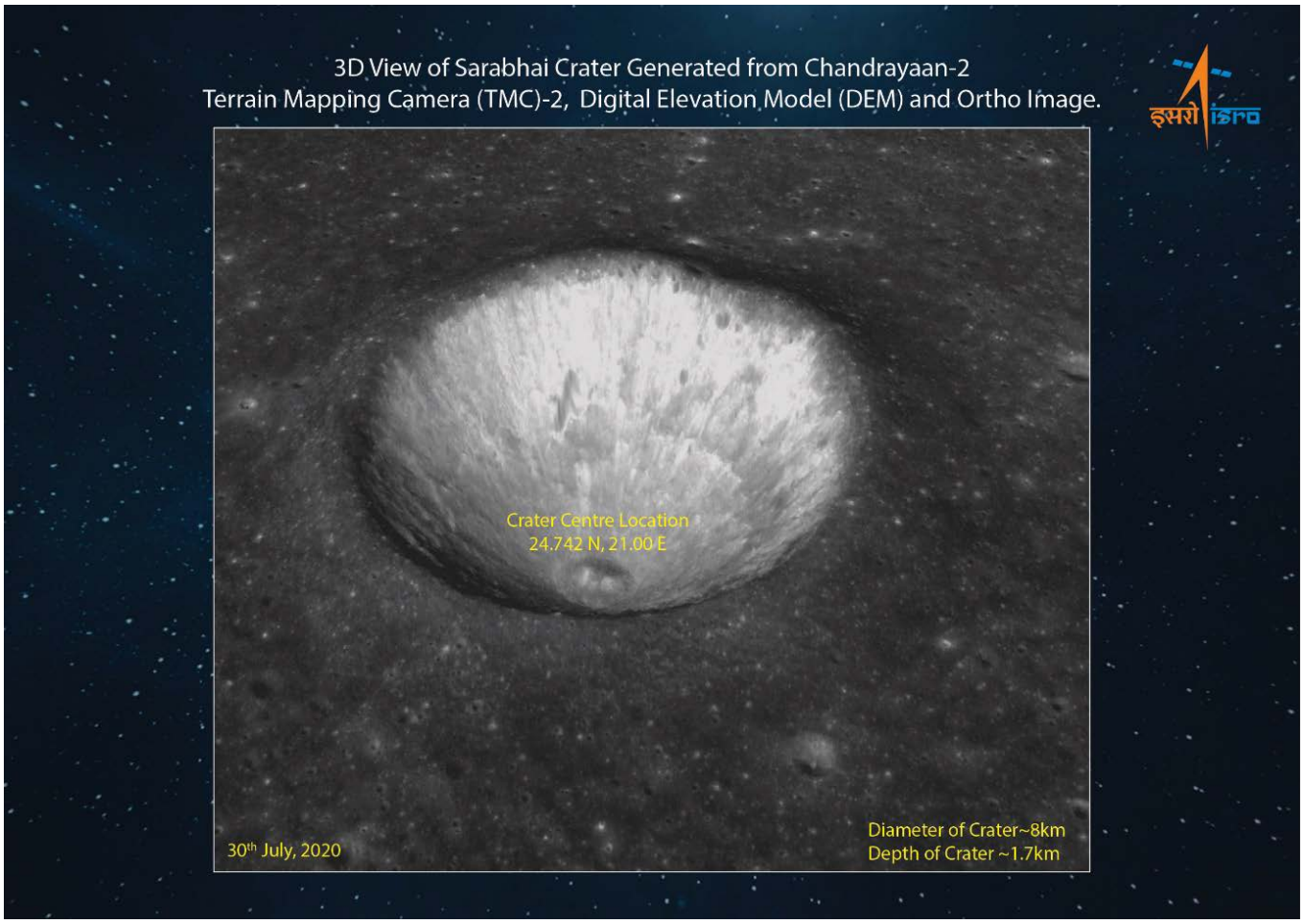


Fig 4: *Sarabhai crater as imaged by Terrain Mapping Camera-2*

- **ADITYA-L1 MISSION**

Aditya L1 shall be the first space based Indian mission to study the Sun. The spacecraft shall be placed in a halo orbit around the Lagrangian point 1 (L1) of the Sun-Earth system. A satellite placed in the halo orbit around the L1 point has the major advantage of continuously viewing the Sun without any occultation/eclipses. This will provide a greater advantage of observing the solar activities. The spacecraft carries seven payloads to observe the photosphere, chromosphere and the outermost layers of the Sun (the corona) using electromagnetic and particle detectors. Using the special vantage point of L1, four payloads directly view the Sun and the remaining three payloads carry out in-situ studies of particles and fields at the Lagrange point L1, thus providing

important scientific studies of the propagatory effect of solar dynamics in the interplanetary medium.

The suits of Aditya L1 payloads are expected to provide most crucial informations to understand the problem of coronal heating, coronal mass ejection, pre-flare and flare activities and their characteristics, dynamics of space weather, propagation of particle and fields etc. The payloads are at various stages of development. The spacecraft is planned to be launched in the year 2022.

- **X-RAY POLARIMETER SATELLITE**

XPoSat (X-ray Polarimeter Satellite) is India's first dedicated polarimetry mission to study various dynamics of astronomical sources in extreme conditions. The spacecraft will carry two scientific payloads in a low earth orbit. The primary payload POLIX (Polarimeter Instrument in X-rays) will measure the polarimetry parameters (degree and angle of polarization) in medium X-ray energy of 8-30 keV photons of astronomical origin. The XSPECT (X-ray Spectroscopy and Timing) payload will give spectroscopic information in the energy range of 0.8-15 keV. Both these payloads are at various stages of development. The spacecraft is planned to be launched in 2021.

3. SPACE SCIENCE RELATED ACTIVITIES/ PROMOTION SCHEMES AND PROGRAMMES

- **SPACE SCIENCE ACTIVITIES:**

➢ **Space Science research activities rocket and satellite experiments, multi-agency sponsored projects** are all co-ordinated from ISRO HQ. The APEX Science Board of ISRO represented by scientists of the country and chaired by former ISRO Chairman, Shri A.S. Kiran Kumar, recommends the conduct of various space science research activities and advises ISRO on the long term planning and promotion of space science research in the country. The detailed co-ordination and implementation of the space science programmes are carried out through the Space Science Programme Office (SSPO) at ISRO HQ.

➢ **INDIAN SPACE SCIENCE DATA CENTER (ISSDC)**

The Indian Space Science Data Centre (ISSDC) is the state-of-the-art facility for hosting the data received from all space science missions of ISRO. Established ahead of the Chandrayaan-1 mission in 2008, ISSDC is known for its high-end servers and processing capabilities with enterprise-class data storage. ISSDC architecture is capable of supporting multiple missions in an automated and uninterrupted manner. This data centre, located at the Indian Deep Space Network (IDSN) campus in Bangalore, is responsible for the Ingest, Processing, Archive and Dissemination of the payload data and related ancillary data for Space Science missions. The primary users of this facility are the principal investigators of the science payloads. In addition to them, the data is made accessible to scientists from other institutions and also to the general public through registration, after the lock-in period.

Since its inception, ISSDC has served various missions and successfully caters the needs of project. Recently, the major upgradation and augmentation of data center activities were carried out to cater the requirements of existing and upcoming missions and refresh the ISSDC systems to avoid original equipment manufacturer (OEM) support issues. The entire data center upgradation has been carried out in well planned and phased manner which enables ISSDC to provide High End Computer systems, ~170 servers, High Performance Peta Scale storage Solution, SAN from 4G to 16G, LAN from 1G to 10G, Enterprise class tape library, High Bandwidth One Way Gateway (OGW), Up-to-date IT Security, Web Vulnerability Scanning (WVS) service, Multi-Homed Network for Internet Services, to name a few.

ISSDC has configured the detailed payload data ingestion, processing & dissemination pipeline for Chandrayaan-2. Various new elements are incorporated like PRADAN, IDP, 3D Imaging System with 3D vision kit, High end processing - Decision Support Solution, 16-button TOPO Mouse. ISSDC is also an active member in Archive creation of Data, following international standards such as Planetary Data System Standards version 4 (PDS4) and is member of hosting planetary data in accordance with International Planetary Data Archive. ISSDC has conducted the National level Chandrayaan-2 data user workshop at IDSN in coordination with Space Science Programme Officer (SSPO) during 6-7 Jan 2020 and has also supported the Science Peer Review actively. ISSDC has played a pivotal role in enhancing the PDS-4 experts across the India by conducting the workshop and regularly reviewing the implementation status. Currently, ISSDC is ready to host more than 2200 science data sets which are Peer Reviewed and Long Term Archive (LTA) products for Chandrayaan-2 Orbiter at ISSDC website (https://www.issdc.gov.in)

ISSDC has successfully supported all the required payload operations/processing of Mars Orbiter Mission (MOM) on a regular basis. Special events such as Deimos, Phobos imaging, stellar Imaging were also supported. Total of 3087 MOM Long Term Archive (LTA) products are hosted at ISSDC for general public using the web data portal: MRBrowse (https://mrbrowse.issdc.gov.in/MOMLTA/). The application has many user friendly features to help users to view, search and download data products.

ISSDC has configured the payload data ingestion, processing, storage & dissemination pipeline for AstroSat - a multi-wavelength space observatory, and successfully commissioned it for mission support. The complete proposal based operations of AstroSat was configured during this period and implemented through different proposal cycles like Performance Validation (PV), Guaranteed Time (GT), Calibration (CAL), Announcement of Opportunity (AO) and Target of opportunity (ToO). A total of 17 TB of data comprising of more than 7949 proposals & observations has been disseminated to the proposers through Astro-Browse portal (https://astrobrowse.issdc.gov.in/astro_archive/archive/Home.jsp) hosted at ISSDC with total number of 797 Indian Users, 686 Foreign users from 48 countries. ISSDC has continued its support for all the phases and observation cycles as per mission guidelines.

Recently, ISSDC has taken up the Mass Regeneration of Mega-Tropiques products by implementing the eight number of parallel regeneration chains.

In addition to the aforementioned missions during this period, ISSDC has also carried out payload operations/processing/dissemination for on-going missions like Space-Based Automatic Identification System (AIS-SB) on-board ResourceSat-2 and SARAL.

ISSDC has re-designed its web architecture and hosted various mission specific Web applications for AstroSat, CH1 Browse for Chandrayaan-1 data, MR1 Browse for Mars Orbiter Mission data, ISSDC Website and Generalised Archival & Dissemination System for generalized multi-mission data sets. The AstroSat Payload Proposal System (APPS) is hosted at ISSDC for receiving proposals from Astronomy community for carrying out observations on various celestial sources by individual/all instruments of AstroSat. The end to end exchange of such information between the scientific community, review committees, mission & operations teams has been worked out and implemented for smooth & automatic exchange of such information among all. ISSDC has completed the detailed requirements gathering, proposed the designs and worked out schemes for Multi-mission Proposal Processing System (MPPS) development for readiness of ISSDC to support Aditya-L1 and XPoSat missions.

The facility is continuously getting enhanced with a motto of “providing Quality Data and Quick services” to future lunar, Planetary and space science missions of ISRO.

• SPACE SCIENCE SCHEMES AND PROGRAMMES

➢ Sponsored Research (RESPOND) Programme

RESPOND, the Sponsored Research Programme of ISRO supports basic research and developmental projects in the niche areas of Space Science, Space Technology and Space Applications which have linkages with the Indian Space Programme.The primary objective of the RESPOND Programme is to establish strong links with academic institutions in the country to carry out research and developmental projects which are of relevance to space programme and also to develop quality scientific /technical human resources. As part of this initiative, ISRO has also set up Space Technology Cells (STC) at premier institutions in the country like Indian Institute of Technologies (IITs) - Bombay, Kanpur, Kharagpur, Madras, Delhi, Guwahati & Roorkee; Indian Institute of Science (IISc), Bengaluru, Savitribai Phule Pune University (SPPU, Pune) to carry out advanced research in the area of relevance to the future technological and programmatic needs of ISRO.

Further, ISRO is also in the process of setting up 6 Regional Academic Centre for Space (RAC-S), a regional level Initiative in the different regions of the country such as North, South, East, West, Central, and North-East. RAC-S aims to pursue advanced research in the areas of relevance to space technology and applications. RAC-S will act as a facilitator for the promotion of space

technology activities among various institutes and students in the region. This will also inculcate scientific research temper in the student community and will give them an opportunity to work in the advanced field of research. RAC-S will also facilitate and engage other institutes of excellence in the region to take part in the capacity building, awareness creation and research & development activities. ISRO has already signed MoUs with MNIT, Jaipur (Western region) and Gauhati University, Guwahati (North-Eastern Region), NITK Surathkal (Southern Region) and NIT Kurukshetra (Northern Region)

In addition, to attract and nurture the young academia with innovative ideas / research aptitude for carrying out research and developing the Academia–Industry ecosystem for Space Technology, ISRO is in the process of setting-up of Space Technology Incubation Centre (S-TIC) in 6 regions of our Country viz. Central, East, North, North-East, South and West. This will enable the young academia to realize their innovative ideas / research aptitude into space grade components/ elements which can be utilized for space applications, and guide them towards setting-up the future start-ups. S-TIC is already operational in NIT Agartala, NIT Jalandhar and NIT Trichy.

In line with ongoing efforts to promote R& D in space technology through industry as well as academia, ISRO in collaboration with Veer Surendra Sai University of Technology (VSSUT), Burla, Sambalpur, Odisha has set up Veer Surendra Sai Space Innovation Centre (VSSSIC) within its campus at Sambalpur. The objective of this Space Innovation Research lab is to promote and encourage the students in research and development in the domain of Space Science and Technology at VSSUT and other institutes within the region.

Apart from this, the joint R & D activities taken up with the Centre for Nano Science and Engineering (CeNSE) at IISc, caters to the requirements of ISRO in the areas of nanotechnology and nanoscience. The Centre is providing support for the R & D activities, utilization of nanofabrication and characterization facilities by the various centres of ISRO, in addition to training/capacity building.

Further, in order to enhance greater participation and contributions from academia in addition to the ongoing Respond activities, a Centre of Excellence (CoE) on Advanced Mechanics of Materials" has been set up at IISc, Bangalore. The Centre aims at pursuing advanced research in the areas of materials especially non classical continuum mechanics and Geometric and data driven models for space applications. Also, an MoU has been entered into with Central University of Jammu, Jammu for setting up a Centre called Satish Dhawan Centre for Space Science to cater to the emerging Geospatial and Space technology requirements for the development of the region. The proposed centre could be considered as an extension activity of ISRO relevant to that region, managed and maintained by Central University of Jammu.

During this period RESPOND has supported 246 projects from 130 Universities/colleges/National Institutes/research centres and 77 projects sponsored earlier have been successfully completed. Apart from this, under Space Technology Cell activities, 282 projects have been supported and

126 projects have been successfully completed. A number of high quality scientific publications have emerged out of these projects apart from fulfilling the objectives at project level. ISRO has also supported 127 Scientific activities, which included conferences, symposia, workshops, educational and promotional activities in Space Science, application and technology areas having relevance to the Indian Space Programme.

➢ ISRO Geosphere-Biosphere Programme (ISRO-GBP or IGBP)

The Earth's climate is controlled by Land-Atmosphere-Ocean interactions through Geosphere-Biosphere-Atmospheric processes. There are many feedback systems within the Earth, which plays an important role in determining the climate of the earth on various time scales. ISRO Geosphere Biosphere Programme (IGBP), initiated in early eighties, has made significant progress with the active participation from various departments and academic institutions. The thrust of IGBP have been mainly on measuring, modelling and monitoring the human factor in the biological, chemical and physical processes of the Earth system, thereby also understanding the regional factors influencing climate change at various scales. A long term network of observatories spread across the country is operated under IGBP to monitor aerosol, ozone and related trace gases. Meteorological and eddy covariance towers are set up to study atmosphere-land surface interactions and carbon flux measurements across different terrains and vegetation types (Forests and typical agricultural crops). Forest cover is being monitored using an approach which combines in-situ and space borne measurements.

Major ongoing projects include Climate Impact Assessment of Aerosols over India, Network of Observatories for Boundary Layer Experiments (NOBLE), Soil-Vegetation-Atmosphere Fluxes of carbon over different forests and agricultural crops across India, carbon and nitrogen cycling in marine and terrestrial eco-systems, and atmospheric CO_2 monitoring and retrieval. Salient trends observed from IGBP network provides input for Ministry of Environment, Forests and Climate Change communications to United Nations Framework Convention on Climate Change (UNFCC).

IGBP also supports research and development capacity building of Universities & Institutions. The focal ISRO DOS centres carrying out IGBP projects are SPL-VSSC, NRSC, SAC, IIRS, PRL, and NESAC which in turn have collaborations with over 70 institutions/Universities. The research output of IGBP in terms of publications in peer reviewed international and national journals, number of Ph.D. thesis submitted, international and national forums represented etc., provides for a strong building block of research and development activities in scientific arena of the country.

4. NATIONAL FACILITIES FOR SPACE SCIENCE RESEARCH

PHYSICAL RESEARCH LABORATORY

Physical Research Laboratory (PRL) a premier national research institute for basic researches under the aegis of Department of Space. The Laboratory has four campuses, located at Ahmedabad, Thaltej, Udaipur and Mt. Abu The main campus in Navrangpura, Ahmedabad

houses most scientific activities of research and the programmes in Astronomy, Astrophysics and Planetary Science and Exploration are housed at the Thaltej campus. The other two campuses at Mt. Abu and Udaipur, house the Infrared (IR) and the Solar Observatory, respectively.

- **Udaipur Solar Observatory (USO):** The Multi-Application Solar Telescope (MAST) is a newly installed 50 cm aperture modern solar telescope at the island observatory of Udaipur, which is providing high spatial resolution solar images (around 250 km on the solar surface). It is aimed to provide regular measurements of the magnetic field on the solar atmosphere for understanding the origin and trigger mechanism of solar eruptions
- **Mt. Abu Observatory at Gurushikar:**

The PRL Mt. Abu Observatory, situated at the top of the Gurushikhar, peak of Aravali range, at an altitude of 1700 meters above mean sea level. The site is one of the best in the country and extremely good for near-IR wavelength observations up to 2.5 microns. Currently, the Observatory houses a 1.2 m Cassegrain focus f/13 telescope, optimized for infrared and optical observations. The PRL Advanced Radial-velocity All-sky Search (PARAS) to detect extrasolar planets using the radial velocity technique is operational since 2012.

The observatory is also in the process of acquiring a larger 2.5 m telescope to provide a big boost to its scientific programs. The telescope will have active optics control systems with very accurate wavefront error at 70 to 100nm WFS. The primary mirror is expected to have a surface finish quality of about 26nm. This will also have speckle imaging capability with the telescope to good high resolution images of bright stars at a level of 0.25 to 0.35 arcsecs, which will be useful for detecting close stellar binary systems. This will also be an unique facility in the country.

The research activities carried out by PRL during Jan 2018–June 2020 are summarized in Chapter 2.

NATIONAL ATMOSPHERIC RESEARCH LABORATORY

National Atmospheric Research Laboratory (NARL) at Gadanki near Tirupati, is a pioneer Atmospheric research laboratory with a vision to “Developing capability to predict the behaviour of the atmosphere through observation and modelling”. There are currently more than 40 observational facilities in regular operation at NARL. These include MST radar, Rayleigh/ Mie Lidar, Boundary Layer Lidar, Sodium Lidar, Lower Atmospheric Wind Profiler, Sodar, Disdrometer, Optical Rain Gauge, Dual frequency GPS receiver, Automatic Weather Station. NARL is also equipped with High Performance Computing (HPC) system to carry out advance analysis and modelling activities.

The research and development activities at NARL are carried out by seven groups viz., Radar and Applications Development Group (RADG); Ionospheric and Space Physics Group (ISPG); Atmospheric structure and Dynamics Group (ASDG); Clouds and Convective System Group

(CCSG); Aerosols Radiation and Trace gases Group (ARTG); Weather and Climate Research Group (WCRG); Computers and Data Management Group (CDMG). The highlights of NARL activities during Jan 2018- June 2020 is provided in Chapter 3.

SPACE PHYSICS LABORATORY

Space Physics Laboratory (SPL) is one of the premier research institutes in India carrying out front-line research in the realms of atmospheric, space and planetary sciences The motto of the laboratory is "scientific understanding of the energetics, dynamics, and chemistry of the terrestrial and planetary environments, and implications to the society". SPL is also the lead laboratory for the regional atmospheric boundary layer and aerosol characterization, radiative forcing and quantifying atmospheric warming. It is also involved in investigating the terrestrial upper atmosphere in context of its energetics and dynamics.

SPL has been playing active role in ISRO's science missions such as Chandrayaan-1 & 2, Mars Orbiter Mission, Megha-tropiques etc. It is involved in ISRO upcoming solar mission Aditya-L1 and also in the planning of future missions on planetary studies. It is actively involved in research in the specialised areas of space and atmospheric sciences. SPL also coordinates programs of national/international importance like the ISRO-Geosphere Biosphere Programme, etc. while initiating programs in the important area of Space Weather. The research community of SPL conducts major experimental campaigns, at national and international level, using balloons, air crafts, rockets, and research ship cruises from time to time.

Highlights of some of the major scientific activities and accomplishments of SPL during Jan 2018-June 2020 period are given in Chapter 4.

SPACE ASTRONOMY GROUP, U R RAO SATELLITE CENTRE

The Space Astronomy Team along with Space Science Instrumentation Facility (SSIF) at U R Rao Satellite Centre (URSC) is involved in scientific research and instrumentation, in the areas of astronomy and astrophysics, solar physics, planetary science, and space weather.

The primary responsibility of space astronomy team and SSIF is to analyse the scientific and technological requirements of identified proposals, converting the scientific requirement into instrumentation, help them developing the laboratory model of the payload, and oversee the realisation of associated Qualification and Flight payloads. Through these activities, space astronomy team provides domain expertise support for developing new scientific payload from laboratory model to the qualification and flight model. This involves simulation and modelling guidance, student training and establishing commonly required major test systems and science calibration facilities. To facilitate the external institutions, space astronomy team has the resources like simulation expertise, basic infrastructure and system design expertise.

In addition to this, this facility is setup to assist external colleges, universities and institutions in the design, development and realization of space-worthy science payloads.

The Space astronomy team has so far developed and flown various scientific payload experiments like Gamma Ray Burst (GRB) Experiment, Indian X-ray Astronomy Experiment (IXAE), Solar X-ray Spectrometer (SOXS), High Energy X-ray Spectrometer (HEX), Chandrayaan-1 Soft X-ray Spectrometer, Scanning Sky Monitor (SSM), Geostationary RAdiation SPectrometer(GRASP) and Chandrayaan-2 Large Area Soft X-ray Spectrometer (CLASS) in various missions.

The team is currently involved in the realization of scientific payloads for the upcoming space missions XPoSat and Aditya-L1. The research activities carried out by Space Astronomy Group/ URSC during Jan 2018- June 2020 are summarized in Chapter 5.

SPACE APPLICATION CENTRE

Space Applications Centre (SAC), is a major research and development centre of the Indian Space Research Organisation (ISRO). It plays a key role in realizing vision and mission of ISRO. Located at Ahmedabad, SAC is spread across two campuses having multi-disciplinary activities.

The core competence of the centre lies in development of space borne and air borne instruments/ payloads and their applications for national development and societal benefits. These applications are in diverse areas and primarily meet the communication, navigation and remote sensing needs of the country. Besides these, the centre also contributes significantly in scientific and planetary missions of ISRO. The centre designs and develops the optical and microware sensors for the satellites, signal and image processing software, GIS software and many applications for Earth Observation (EO) programme of ISRO. These applications are in diverse areas of Geosciences, Agriculture, Environment and Climate Change, Physical Oceanography, Biological Oceanography, Atmosphere, Cryosphere, Hydrosphere etc.

The facilities at SAC includes highly sophisticated payload integration laboratories, electronic and mechanical fabrication facilities, environmental test facilities, systems reliability/assurance group, image processing and analysis facilities, project management support group and a well-stocked library. SAC has active collaborations with industry, academia, national and international institutes for research and development. The centre also has state-of-art in-house and mobile exhibitions to propagate space technology and applications amongst students and public. Major science/ applications activities of SAC is covered in Chapter 6.

NATIONAL REMOTE SENSING CENTRE

National Remote Sensing Centre (NRSC) is one of the primary centres of Indian Space Research Organisation (ISRO), Department of Space (DOS). NRSC has the mandate for establishment of ground stations for receiving satellite data, generation of data products, dissemination to the users, development of techniques for remote sensing applications including disaster management

support, geospatial services for good governance and capacity building for professionals, faculty and students.

NRSC operates through multiple campuses to meet national and regional remote sensing data and applications needs of the country. Main Campus at Balanagar, Hyderabad provide Administration, Remote Sensing Applications and Aerial Services. The Campus at Shadnagar provide Satellite Data Reception, Data Processing and Dissemination, Earth and Climate Studies and Disaster Management Support. There are five Regional Centres for promoting remote sensing applications for various states. Outreach facility at Jeedimetla in Hyderabad provide training for professionals, faculty and students and for general outreach.

The activities carried out by NRSC during Jan 2018- June 2020 are summarized in Chapter 7.

INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY

The Indian Institute of Space Science & Technology (IIST) is an autonomous institute under the Department of Space (DOS), and a deemed to be University. IIST offers various undergraduate (UG) and postgraduate (PG) programmes in areas that are relevant to space studies. The institute currently offers two B.Tech courses in Aerospace Engineering and Avionics and a Dual Degree (B. Tech + Master of Science/ M. Tech) programme with B.Tech in Engineering Physics and any of the following Postgraduate specializations - (i) Master of Science (Astronomy & Astrophysics) (ii) M.Tech (Earth System Science) (iii) Master of Science (Solid State Physics) and (iv) M.Tech (Optical Engineering).

Apart from this, IIST offers PG programmes in fifteen areas of space science, space engineering and related areas. The academic programmes have been formulated to strengthen the fundamentals, experience the realities through practical work, and enhance the knowledge and understanding in the areas relevant and related to space. Also, the programmes so envisaged ensure adequate exposure in the emerging fields which will lead to experience knowledge synthesis.

The institute recognizes the importance of research in developing future technologies and applications of space research. The expertise of IIST faculties span the various fields of aerospace engineering, avionics, earth and space sciences, mathematics, chemistry, physics and humanities. These faculties are currently guiding over one hundred PhD scholars in various areas of research and teaching to over more than seven hundred students in UG and PG courses.

The major space science activities of IIST are covered in Chapter 9.

INDIAN INSTITUTE OF REMOTE SENSING

Indian Institute of Remote Sensing (IIRS) is a premier institute with a primary aim to build capacity in Remote Sensing and Geoinformatics and their applications through education and training programmes at postgraduate level. It is a constituent Unit of Indian Space Research Organisation

(ISRO), Department of Space, Govt. of India. Formerly known as Indian Photo-Interpretation Institute (IPI), founded in 1966, the Institute is first of its kind in entire South-East Asia. While nurturing its primary endeavour to build capacity among the user community by training mid-career professionals since its founding in 1966, the Institute has enhanced its capability and evolved many training and education programmes that are tuned to meet the requirements of various stake-holders, ranging from fresh graduates to policy makers including academia, industry and NGOs. The major activities during Jan 2018- June 2020 are covered in Chapter 12.

TATA INSTITUTE OF FUNDAMENTAL RESEARCH

The Department of Astronomy and Astrophysics-TIFR is Located in the scenic Mumbai campus. The department carries out cutting edge research in theoretical and observational astrophysics with an active interest in instrumentation. The observations are carried out using ground based facilities as well as balloon-borne and satellite-borne instruments. This is supplemented by the work done in Radio Astronomy and High Energy Cosmic Rays by other groups in the Institute. The research activities carried out by TIFR Astronomy and Astrophysics during Jan 2018- June 2020 are summarized in the Chapter 13.

- **Giant Meter-wave Radio Telescope, Pune (National Centre for Radio Astrophysics)**

The GMRT consists of thirty 45 m diameter antennas spread over a 28 km region. Twelve of the antennae are in a compact, quasi randomly distributed array with a diameter of about 1 km. The remaining antennas are distributed along 3 arms of length ~14 km in a Y-shaped configuration (NorthWest, NorthEast and South). The longest baseline is about 28 km and the shortest is about 100 m, without foreshortening. The telescope (with centre of the array at latitude=19.1 deg N, Longitude = 74.05 deg E) is located near Khodad village, which is about 80 km north of Pune.

The GMRT has been open to the international community of users since early 2002, via a proposal submission and approval scheme that presently runs two observing cycles in each year. Over the last 15 years of operations, the GMRT has produced several interesting new results and discoveries in different areas of astrophysics, and an average of more than 40 papers per year in international journals feature results from data obtained with the GMRT.

In March 2019, the GMRT formally completed a major upgrade of its capabilities, which has increased its frequency range to have near seamless frequency coverage from 110 to 1500 MHz and a maximum bandwidth of 400 MHz, along with improved sensitivity receivers with better dynamic range. This has improved the sensitivity of the GMRT for continuum imaging by more than a factor of three, along with a similar benefit for pulsar observations, and has also widened the span of redshifts over which the line from neutral Hydrogen from different reaches of the Universe can be observed. The upgrade is also accompanied by installation of a revamped and modern

servo system on all the antennas, a new generation monitor and control system, and various improvements in infrastructural and computational facilities. Major initiatives for mitigation of radio frequency interference have also been implemented for the upgraded observatory, such as automated detection and avoidance of interference from satellite signals, and real-time excision of interference signals from the signal chain for each antenna.

The work on the upgraded GMRT was accorded a major recognition in February 2020 – the Zubin Kembhavi award 2019 of the Astronomical Society of India for "Observational and Instrumentation work in Astronomy and allied fields" was awarded to 'Team GMRT' from NCRA.

- **Ooty Radio Telescope, Ooty (Tata Institute of Fundamental Research)**

The Ooty radio telescope (ORT) continued its program of long term monitoring of turbulence in the inner heliosphere. In addition, the recently started pulsar observations using the new backend (PONDER) were continued. This included studies of the ISM via a scattering survey of a large number of pulsars, studies of giant pulses, as well as of monitoring of glitching pulsars. It is also being used to monitor pulsars as part of the Indian Pulsar Timing Array (InPTA) program. The installation of the hardware for the Phase I of the upgraded system (OWFA) were completed, and characterization and calibration observations with this Phase I system were initiated. Software was developed for post-correlation beam forming i.e. from the calibrated visibilities produced by the correlator. A new hydrogen maser based time and frequency standard has been installed and commissioned.

- **National Balloon Facility (NBF), Hyderabad (Tata Institute of Fundamental Research)**

The Balloon Facility of Tata Institute of Fundamental Research has expertise in the field of scientific ballooning. The Balloon Facility designs, fabricates and launches various zero pressure polyethylene balloons for high altitude balloon-borne experiments with 100% payload recovery and also launches / hoists tethered balloons (Kytoons) for atmospheric boundary layer studies. The facility has an in-house balloon production facility as well as ground facilities for balloon launching and recovery operations, a control room for handling the data (telemetry) and command (tele-command) operations using S-band telemetry and balloon tracking capabilities. The zero pressure balloons designed and fabricated at Balloon Facility are mainly used in the field of Astronomy and Atmospheric sciences. The Balloon Facility has been providing its support for various balloon experiments of National and International research institutes. Recently, the Balloon Facility provided launch and recovery support to ISRO (NARL) and NASA for studying the Asian Tropopause Aerosol Layer (ATAL) during the Indian south west monsoon seasons (August-2018 and July-2019) and to SPL-VSSC for studying the turbulence and atmospheric gravity waves in the upper troposphere and lower stratospheric regions. Recently, the Balloon Facility has specially designed, fabricated and supplied two zero pressure balloons for manned flights to international user community.

INDIAN INSTITUTE OF ASTROPHYSICS

Indian Institute of Astrophysics (IIA) is India's premier research institution devoted to studies in astronomical sciences. IIA was established in the year 1971 as an autonomous research Institute wholly financed by the Government of India. Presently, IIA functions under the administration of the Department of Science and Technology. IIA main campus is located in Bengaluru.and the observational facilities are spread across the country, in four major field stations - Hanle (Ladakh, Jammu and Kashmir), Gauribidanur (Karnataka), and Kavalur and Kodaikanal (Tamilnadu). The Hosakote campus in the Bengaluru Rural District houses the Centre for Research and Education in Science and Technology (CREST). The Himalayan Chandra Telescope (HCT) in Hanle is remotely operated from this centre via a dedicated satellite link. IIA has its own optical, infrared, radio and high altitude gamma ray array facilities.

With a strength of over 70 faculties (Scientists + Engineers) and a similar strength of students plus postdoctoral fellows, IIA conducts research vigorously in the fields which are broadly classified as, Sun and Solar System, Stellar and Galactic Astronomy, Extragalactic Astronomy & Cosmology, Theoretical Astrophysics & Physics, Space Astronomy and Instrumentation. The research activities carried out by IIA during Jan 2018- June 2020 are summarized in Chapter 14 of this report.

INTER-UNIVERSITY CENTRE FOR ASTRONOMY AND ASTROPHYSICS

The Inter-University Centre for Astronomy and Astrophysics (IUCAA) is an autonomous institution set up by the University Grants Commission (UGC) of India to promote the nucleation and growth of active groups in astronomy and astrophysics at Indian universities. IUCAA aims to be a centre of excellence within the university sector for teaching, research and development in astronomy and astrophysics. IUCAA's computer facilities are accessible to the entire Indian University sector for astronomy domain applications.

The Radio Physics Laboratory setup in IUCAA, in collaboration with the National Centre for Radio Astrophysics (NCRA), Pune, continues its task to train motivated science and engineering students nationwide in the use of Radio Telescope, and introduce them to Radio Astronomy Science Education.

Besides conducting vigorous research programmes of its own, the Centre enables workers from Indian universities, teachers as well as students, to visit the Centre to use the facilities for various durations. Through the Associateship Programme which was started in 1990, the faculty members from Indian universities and colleges, along with their students may visit IUCAA and use the facilities for their research work. A visiting associate selected under this programme can visit maximum 365 days in a tenure of 3 years, as per their convenience.

Through the Public Outreach Programme, school and college students are invited to visit the Muktangan Vidnyan Shodhika (Science Exploratorium) in IUCAA campus, where they discover the joy of learning science by do-it-yourself. During summer vacation, school students are invited

to do week-long projects with guidance from IUCAA members. Similar programmes have been conducted for the school students around the rural region of IUCAA Girawali Observatory.

Presently IUCAA is also involved in SUIT (Solar Ultraviolet Imaging Telescope) payload development in collaboration with ISRO for India first solar mission Aditya-L1. IUCAA also run ASTROSAT support cell to train and help the ASTROSAT user community in coordination with ISRO.

The activities carried out by IUCAA during Jan 2018- June 2020 are summarized in Chapter 15 of this report

RAMAN RESEARCH INSTITUTE

The Raman Research Institute (RRI) is an autonomous research institute engaged in research in basic sciences. RRI contributes to the understanding and scientific comprehension of natural phenomena right from the sub-atomic to mesoscopic to cosmological scales through experiments, theoretical modeling and an active combination of both. The main thrust areas of RRI research focus in niche fields of 1) Astronomy & Astrophysics including theoretical astrophysics, observational astronomy, and experimental Radio and X-ray astronomy, 2) Light & Matter Physics including cold atoms, ions, molecules, quantum communications and computing, and intense laser produced plasma, 3) Soft Condensed matter including research in liquid crystals, nano-composites, colloids, chemistry and biological physics, and 4) Theoretical Physics including General Relativity, Foundational quantum mechanics, soft matter physics, and classical and quantum Statistical Mechanics and Gravity.

RRI is also involved in the development of POLIX instrument which is aimed to detect X-ray polarization from bright astronomical sources in medium X-ray energy range. Another activities covers the development of space based quantum entanglement experiment. Recently RRI has also initiated activities towards THz astronomy. The highlights of the research activities carried out by RRI during Jan 2018–June 2020 are summarized in Chapter 16.

- **Gauribidanur Radio Observatory**

The Observatory has a variety of radio telescopes: a low frequency antenna array functioning at 34.5 MHz for observations of radio emission from Sun, pulsars and other galactic, extragalactic sources; a radio heliograph operating in the frequency range 40-120 MHz for imaging the solar corona in the height range of about 0.2-0.8 solar radii above the solar photosphere; a radio polarimeter for observations of circularly polarized emission in the above height range; a radio spectrograph for obtaining dynamic spectrum of the transient burst emission from the solar corona, again in the same height range. The aforementioned facilities at the Observatory are unique in their corresponding frequency range. This observatory is jointly operated by Indian Institute of Astrophysics and Raman Research Institute, Bangalore.

ARYABHATTA RESEARCH INSTITUTE OF OBSERVATIONAL SCIENCES

Situated adjacent to the picturesque hill town of Nainital, ARIES (Aryabhatta Research Institute of Observational Sciences) is one of the leading research Institutes which specializes in observational Astronomy & Astrophysics and Atmospheric Sciences. The main research interests of Astronomy & Astrophysics division are in solar, planetary, stellar, galactic and extra-galactic astronomy including stellar variabilities, X-ray binaries, star clusters, nearby galaxies, quasars, and inherently transient events like supernovae and highly energetic gammaray bursts.Research focus in Atmospheric Sciences division is mainly in the lower part of the atmosphere and covers the studies on aerosols and trace gases. Moreover, to strengthen the scientific contribution, the Institute has extended its horizon to theoretical and numerical studies in Relativistic Astrophysics. The unique position of ARIES (79° East), places it at almost in the middle of 180° wide longitude band, between Canary Island (20° West) and Eastern Australia (157° East), and therefore complements observations which might not be possible from either of these two places. ARIES has made unique contribution from time to time.

The Institute hosts three telescopes of apertures 104-cm, 130-cm and 3.6-mDOT. There is a 15-cm telescopes dedicated for solar observations. The 104-cm optical telescope is being used as a main observing facility by the ARIES scientists since 1972. It is equipped with 2k x 2k, and 1k x 1k liquid N cooled CCD cameras, fast photometer, spectrophotometer, and standard astronomical 2 filters. The telescope uses a SBIG ST-4 camera for auto-guiding through an auxiliary 20-cm telescope.

In order to carry out observations in the frontier areas of astronomy, the Institute has installed 130-cm and 360-cm optical telescopes at a site called ‘Devasthal’ at a distance of ~ 60-Km from ARIES, which has the advantages of having dark skies and excellent observing conditions. There are different instruments for observation of physical and optical properties of aerosols and trace gas. An 84-cm micro-pulse LIDAR system for high altitude studies of aerosols and a ST Radar (Stratosphere Troposphere Radar) to measure winds speed up to an altitude of around 20 km is also being setup.

The activities carried out by ARIES during Jan 2018- June 2020 are summarized in Chapter 17 of this report

INDIAN INSTITUTE OF GEOMAGNETISM

The Indian Institute of Geomagnetism (IIG) has an enviable antiquity of over 175 years, which was instrumental in spawning geomagnetism in the Indian subcontinental region. It has evolved from being a data gathering organization to using long series geomagnetic data, to tackle applied aspects that benefit society, in an obvious and abstruse ways. Indian Institute of Geomagnetism (IIG) was given a full-scale mandate to pursue geomagnetic and allied field research in 1971. It has been an autonomous institution since its inception and is now functioning directly under the Department of Science and Technology, Government of India. The evolution of geomagnetism in the country has been interminably linked with the growth of this institution.

A significant contribution to research in the field of geomagnetism started in India as back as in 19th century. Geomagnetic observations commenced in India and rest of the world almost concurrently. The first magnetic observations in India were started at Madras in 1822, followed by the recordings at Simla (1841), Trivandrum (1841) and Colaba (1841). Among these, only Colaba observatory continued uninterrupted since 1841. The combined observations at Colaba and Alibag observatories provide the longest series (nearly 175 years) of magnetic field data.

IIG conducts basic and applied research in Geomagnetism and allied fields like Solid Earth Geomagnetism/Geophysics, Magnetosphere, Space and Atmospheric Sciences. IIG has a number of active research groups involved in theoretical, experimental, and observational work. The Institute has a modern laboratory for design and fabrication of instruments used in Geomagnetism and allied fields. Geomagnetism is a multi-disciplinary science and thus provides research opportunities for Physicists, Geophysicists, and Earth Scientists. Geomagnetism, by its very nature, is also a global science and often involves collaboration with scientists from other countries. The Institute also supports a World Data Centre for Geomagnetism (WDC, Mumbai), which is the only International centre for Geomagnetic data in South Asia and caters to the needs of Space and Earth Scientists and researchers from various universities and research institutions.

The major activities of IIG in the duration Jan 2018-June 2020 are summarized in Chapter 19.

CONFERENCES / SYMPOSIA

20th National Space Science Symposium (NSSS-2019)

The twentieth National Space Science Symposium (NSSS-2019) was held at the Savitribai Phule Pune University, Pune along with co-hosts, IUCAA and NCRA during January 29 – 31, 2019. The main aim of this symposium is to provide a scientific forum to present new results in the areas of atmospheric science, space science, planetary exploration and astronomy and astrophysics. The broad areas covered during the symposium are space and ground based astronomy and astrophysics, planetary science/ exploration, Sun and its interaction with the Earth and other planetary systems, magnetosphere, ionosphere, thermosphere and middle atmosphere phenomena, space based oceanography, meteorology and tropospheric studies, climate changes and geosphere-biosphere interaction processes. NSSS is being conducted once in two years.

The symposium consisted of three Special Plenary Sessions (Future Space Science Missions; Capacity Building for Space Science; New Frontiers in Atmospheric science), a popular lecture on “Reaching out from Earth-challenges of space exploration”, two interdisciplinary lectures and five parallel sessions with contributory oral and poster presentations.

About 500 participants, which includes research students and scientists from various institutions and universities attended the symposium. Overall, about 180 oral presentations and 263 poster

presentations were made with representation from almost all states in the country. During the symposium, best Oral and Poster Cash Prize Awards were distributed to young scientists.

Fig 5: *Dignitaries and Participants during NSSS 2019.*

Space Research in India is carried out using the space and ground based facilities established and operated by ISRO as well as other institutions. The outcome of these research activities is presented in the following chapters of this report.

PHYSICAL RESEARCH LABORATORY (PRL)
AHMEDABAD

The Physical Research Laboratory (PRL) is primarily engaged in fundamental research on various topics. They are (1) Astronomy & Astrophysics; (2) Solar Physics; (3) Space and Atmospheric Sciences; (4) Planetary Sciences; (5) Geosciences; (6) Atomic, Molecular and Optical Physics; and (7) Theoretical Physics. Each of these major research programs of PRL has several sub-programs within it. These major programs and sub-programs have evolved over the last seven decades of focused research by PRL researchers. Each of the above scientific programs is aimed at understanding the nature and fundamental processes using a variety of ground- and space-based and remote sensing observations, and theoretical modeling and numerical simulations.

A. OVERALL SPACE RESEARCH ACTIVITIES:

Space Research in PRL comprises of diverse topics in Astronomy and Astrophysics, Solar Physics, Space and Atmospheric Sciences, Planetary and Geosciences, and Astrochemistry. Some of the major research focus in these fields involves:

- Investigations in the optical, infrared, X-ray, and radio wavelength bands to understand some of the outstanding problems related to galactic and extragalactic cosmic phenomena, such as star formation, stellar evolution, interstellar medium, binary stars, pulsars, active galactic nuclei, and giant radio galaxies.
- Research studies to understand radiative, chemical, ionization, and dynamical processes in the Earth's atmosphere by employing in-situ rocket and balloon-borne experiments, ground-based optical and radio probing, laboratory experiments, theoretical simulation, and modeling of the Earth's upper atmosphere.
- To study the origin and evolution of the solar system with a focus on inner planets, Moon, and minor bodies. Physical and chemical processes in planetary lower and upper atmospheres and ionospheres using observations, theoretical simulations, and modeling of planetary atmospheres and comets.
- The physics of solar oscillations, the evolution of sunspots, sunspot fine structure, magnetohydrodynamic processes in the solar atmosphere, coronal heating, solar eruptions, solar activity, and its impact on space weather.
- Aerosol geochemistry to understand the aerosol cycle, a study of fundamental atmospheric processes affecting atmospheric aerosol, and their implications to atmospheric chemistry, air quality, aquatic ecosystem, and climate change,
- Applications of stable and radioactive isotopes to characterize and determine the timescales of processes occurring in the early solar system application of isotopes in identifying sources, transport, and transformation processes.

- Development of instruments for planetary and space exploration.

B. MAJOR FACILITIES/ INSTRUMENTATION DEVELOPED.

- **Optical Aeronomy Laboratory** was set up in 2019 in the Thaltej campus of PRL to carry out experiments to measure day and nighttime airglow emissions. In this laboratory, in-house design and development of optical techniques/instruments are carried out. The optical instruments are designed to operate at different spectral resolutions and over varying fields of view (4 - 140 degrees) that are capable of operation in both daytime and nighttime conditions. The focus of the research carried out using the state of the art instruments developed in the Optical Aeronomy laboratory is to understand, characterise, and quantify the effects of upper atmospheric wave dynamics in both day and nighttime conditions.
- **Adaptive Optics** is a technique that helps in real-time correction of the aberrations in an optical system due to turbid media. It is found useful in astronomy and vision sciences for high-resolution imaging, free-space optical communication, laser beam shaping, and many more. USO is involved in the research of Adaptive optics with a primary aim of achieving high-resolution solar observations. This laboratory is one of the kind of state-of-art AO laboratory in the country for research and development activities related to high-resolution imaging.
- **e-CALLISTO**, **C**ompound **A**stronomical **L**ow-Frequency **L**ow-Cost **I**nstrument for **S**pectroscopy and **T**ransportable **O**bservatory, is used for the observations of solar radio bursts and radio frequency interference monitoring for astronomical science. The e-CALLISTO system is a valuable new tool for monitoring solar activity and for space weather research.
- **MFOSC-P,** Mt. Abu Faint object spectrograph, and camera – Pathfinder (MFOSC-P) instrument was commissioned on PRL 1.2m Telescope at Mt. Abu in February 2019, and a series of commissioning tests and science observations were carried out to ensure and confirm the on-sky performance of the instrument in its spectroscopy and imaging modes.
- **Planetary Remote Sensing Laboratory**, one of the major goals of planetary remote sensing, is to decipher surface composition through reflectance/imaging spectroscopy. In order to aid in the analysis of the remotely acquired data and to assist in detector optimization for future missions, a Planetary Remote Sensing Laboratory has been established at PRL, Thaltej campus. Scientists plan to carry out reflectance spectroscopy of planetary materials (such as meteorites & returned samples) and analogues under simulated conditions. The measurements will be carried out as a function of fluctuations in viewing geometry, grain size variations, mineral mixtures, and changes in environmental conditions.

C. MAJOR RESULTS

- Discovered a sub-Saturn or super-Neptune size planet (mass about 27 Earth Mass, and size 6 Earth Radii) around a Sun-like star. The new planet is known as EPIC 211945201b or

K2-236b. This discovery is made by measuring the mass of the planet using the indigenously designed “PRL Advance Radial-velocity Abu-sky Search” (PARAS) spectrograph integrated with 1.2 m Telescope at PRL’s Gurushikhar Observatory in Mount Abu, India. Only 23 such exo-planetary systems (including this discovery) are known to this date with masses between 10 and 70 Earth mass and size of 4 to 8 Earth radii with such precision. This discovery is important for understanding the formation mechanism of such super-Neptune or sub-Saturn size planets that are too close to the host star, as well as planet formation around Sun-like stars. Further, PARAS is the first of it’s kind of spectrograph in Asia, and among a very few spectrographs that exist around the world, which can measure, with such precision, the mass of a planet going around a star.

- Unusually large electric field disturbances in the dip-equatorial ionosphere are observed when two consecutive interplanetary coronal mass ejections (ICMEs) hit the terrestrial magnetosphere resulting in a strong geomagnetic storm during 6-8 September 2017. These unusually large electric field perturbations caused significant changes in the E region current and F region vertical drift as well as plasma fountain over low latitudes.

- The distance of magnetopause, bow shock, shape of the magnetopause have been estimated using radio data, numerical as well as empirical models. It is found that on two instances between 1968 and 1991, the magnetopause stand-off distance dropped to values close to 6.6 earth radii for a duration ranging from 9-11 hours. This is a very important finding as it represents a clear and present danger to our satellite systems in the event of a large CME impact, especially given the fact that very large CMEs have been known to occur in weak solar cycles.

- A comparative study of interplanetary coronal mass ejections (ICMEs) observed in solar cycle (SC) 23 & 24 shows that although the number of ICME events in SC24 was less compared to the previous cycle, the fraction of magnetic clouds were much higher during SC24 than SC23 (60% to 41%). The analysis of magnetic clouds and ejecta observed in the same cycle supports the hypothesis that all CMEs have a flux rope structure and that the trajectory of the CMEs essentially determines the observed ICME structure at 1 AU.

- A novel approach using ground-based optical neutral oxygen dayglow emission measurements has been developed to estimate the daytime equatorial (E x B) vertical drifts, wherein it has been demonstrated that the extent of asymmetric nature in diurnal variation in oxygen emissions over an off-equatorial region (Hyderabad, India) is found to be proportional to the E x B vertical drift over the magnetic equator. This new approach provides an alternative method for obtaining vertical drifts to enable systematic investigations of equatorial electrodynamics.

- Signatures of solar cycle dependence of dominant atmospheric tides are observed in the mesosphere and lower thermosphere over an extratropical station. Both diurnal and semidiurnal tides show a high correlation in Autumn and the least correlation in Summer. In general, such a relationship between the tides and solar flux is found to be most prominent in

solar maxima. Further, amplitudes and periods of the quasi-two-day wave exhibit relationship with the solar flux, with higher values in solar minimum as compared to solar maximum.

- The variations in the aerosol-induced atmospheric heating rate that arise due to the differences in the chemical composition of aerosols (single scattering albedo) on temporal (season), spatial (urban vs. high altitude remote), and on vertical (surface vs. column) scales obtained over the same region over distinct environments (locations), provide regional bounds for aerosol radiative effects, and will be crucial for regional climate impact assessment.
- Results show that the mixing characteristics of refractory black carbon aerosols are different for different sizes of particles, which would result in large variations in the physicochemical properties (i.e., hygroscopic and optical properties) of aerosols. These findings from an urban location in the tropics, the first and unique, are crucial for determining the impact of black carbon aerosols on cloud condensation nuclei activation process and can serve as inputs in climate models for aerosol-cloud-radiation interaction studies.
- In recent studies over the Arabian Sea, the relations between the levels of important oceanic biogenic volatile organic compounds (BVOCs) such as isoprene and light alkenes in marine air and the physical and biological parameters of surface seawater of the Arabian Sea has been established. Large emissions of BVOCs from the oligotrophic water highlight the implications of the Arabian Sea 'Paradox' on regional atmospheric chemistry in view of elevated emissions of BVOC from seawater and NOx from shipping activities.
- It has been shown that widespread enhancement in fine particulate matter (PM2.5) over the Indo-Gangetic Plain towards winter is linked very closely with atmospheric dynamics.
- The impact of mesoscale gravity waves on the microphysical changes in cirrus clouds over the subtropical Indian region using Raman lidar, satellite, model simulations, and reanalysis data sets has been revealed. It has been shown that the cirrus clouds are formed from the convective outflow of large-scale convergence zone extending from south-west to northeast Indian region. These clouds are modulated by the upward propagating gravity waves with time periods of around 40 and 20 minutes over the Raman lidar observational site, Ahmedabad, India.
- Multi-wavelength observations of a long-duration solar flare caused by the eruption of a hot channel from a coronal sigmoid were carried out, which shows hard X-ray emission from a magnetic flux rope.
- Observations provide evidence of the distinct rebuild-up of net Lorentz force in between the successive flares and its abrupt downward changes during each flare in active solar regions. This evolutionary pattern of net Lorentz force, which is responsible for the build-up and magnetic energy release, has significant implications for the forecasting of recurrent large eruptive flares from the same active region and hence the chances of interaction between the associated CMEs.

- Observations of small-scale precursor activities leading to the destabilization of a meta-stable flux rope suggest that pre-flare emission can be initiated by locations of a strong photospheric current of opposite sign situated adjacent to each other and further, a series of such small-scale activities can eventually lead to triggering of a flux rope eruption.
- By implementing an automatic detection algorithm for solar filaments on full-disk Hα images, the time of initiation of an eruption of filaments has been estimated. These timings, when compared with that of associated flare observed in EUV, help to establish the temporal connection of eruption filaments as precursors to flare–CMEs and hence is a very useful method for space weather assessment.
- The temporal and spatial variability of chemical mechanisms is studied for the Martian atmosphere. It is observed that O_3 is in photochemical equilibrium up to 30 km (aphelion) and up to 45 km (perihelion), for which hygropause is proposed as a marker for ozone seasonal variability.
- Total columnar ozone and dust are retrieved from the Mars Express spectral data for two Martian years. In southern tropical latitudes, columnar O_3 is increased during the MY28 global dust storm, indicating the radiative impact of dust on O_3. From GCM/SPICAM observations, atmospheric dynamics is found to have more effect on O_3 during winter over the southern polar region.
- The geological evolution of the Grimaldi Basin on the Moon has been deciphered using remote sensing datasets from Chandrayaan-1 M3, and LRO-WAC, NAC. It has been found that the basin was experiencing volcanism and tectonic activities during the Copernican period. Thus, late-stage volcanism on the Moon has a greater spatial span than understood earlier.
- A study has established that Giant flares took place from the embryonic Sun. Such super-flares has been calculated to be about a million times stronger in intensity compared to the highest X-class flare observed from the modern Sun.
- A photochemical model is developed to study the forbidden atomic carbon, nitrogen, and oxygen optical emission lines in comet C/2016 R2. The mean photodissociation yield of CO, producing ~1% C(^{1}S) and difficult to measure in the lab, is constrained using the model and observations. In this water-depleted comet, CO_2 can be a significant production source of atomic oxygen, rather than H_2O.
- New models of regolith and water ice (volatile) mass escape rates due to micrometeorite impact are developed using Galileo dust observations. Upper limits of mass escape rates of regolith and water ice for the micrometeorites impacts are calculated. It is found that Moon loses its water ice (volatile) at a rate of ~6.3 kg year^{-1} due to the micrometeorite impact.
- An unusually bright structure of 1800 km^2 is found on the lunar, equatorial farside near Dufay crater, which has a strong 3μm absorption feature. The feature is 30% stronger than

surrounding at the local midday, and it is unique of its kind. The structure could be due to a thin layer formed by the recent fall of meteoritic/cometary material with high OH/H_2O content, being detectable by its pronounced 3μm absorption band.

- Five new skylights have been discovered in the Hebrus Valles region of Mars (20^{0}40'31.9" N, 126^{0}23'56.2" E) using remote sensing data from MRO (Mars Reconnaissance Orbiter; NASA) and Mars Odyssey (NASA). These are indicative of the presence of caves in the subsurface, which are sites of scientific importance for future exploration of the Red planet due to their astrobiological significance.

- A photochemical model is developed to study the forbidden atomic carbon, nitrogen, and oxygen optical emission lines in comet C/2016 R2. The mean photodissociation yield of CO, producing ~1% C(^{1}S) and difficult to measure in the lab, is constrained using the model and observations. In this water-depleted comet, CO_2 can be a significant production source of atomic oxygen. The first-ever observed emissions and the modeling works suggest radial transport to be the dominant loss mechanism for N(^{2}D) in the coma.

- A model to study the photochemical processes of ultraviolet atomic line emissions in comet 67P is developed. Assuming electron impact to be the only excitation mechanism, the Rosetta Alice spectrometer observations are used to derive the electron density. The modeling results suggest the observed HI, OI, and CI emission lines are being controlled by photodissociation of neutrals rather than electron impact excitation as thought earlier when the comet has a gas production rate of $10^{27}s^{-1}$ or more.

- Venus Express observations of whistler-mode waves around 250 km altitude were analysed. The results demonstrated the presence of a lightning source below the ionosphere.

- For the first time, the concept of chemisorption is used to study the formation of molecules in astrophysical environments. Depending upon the depth of the potential well of the chemisorption site, it can form molecules up to 800 K or more. Until this work, astrochemical models treated grain surface chemistry solely by physisorption, which is only efficient at low temperatures (< 200 K). Thus, the use of chemisorption will improve the molecular abundances in astrophysical environments having dust temperature above 200 K, e.g., protoplanetary disks, carbon stars, planetary atmospheres, among others.

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NATIONAL ATMOSPHERIC RESEARCH LABORATORY
GADANKI

National Atmospheric Research Laboratory (NARL), Gadanki, an autonomous organization under the Department of Space, is engaged in research in atmospheric and space sciences and Technology. The activities at NARL primarily focus on experimental research on atmosphere and space, development of radio and optical instruments and modelling for weather and climate research. NARL has a vibrant research program, capacity building and public outreach activities. NARL also provides necessary experimental and computational facilities to atmospheric science community, both national and international, for conducting research.

NARL research has revealed the inverse relationship between solar EUV flux and daytime 150-km echoes and brought out the complex interplay among photochemistry, wave particle interaction and neutral/electrodynamics, which have challenged the recently proposed photo-electron induced plasma wave processes at the origin of the echoing phenomenon. Multi-instrumented observations and analysis coupled with numerical simulation have provided vital clue on the seeding and forecasting capability of equatorial plasma bubbles (EPBs), which are detrimental for satellite-based navigation/communication applications. For the first time, observation based daytime vertical plasma drift model has been developed for the Indian sector. Also, the response of the daytime ionosphere in terms of total electron content (TEC) to the geomagnetic storm has been brought out in a consolidated manner based on a large database of geomagnetic storm events. Research on Martian ionosphere revealed latitudinal shift of the magnetically controlled density structures highlighting the role of atmospheric dynamics.

A detailed investigation on the Asian Tropopause Aerosol Layer has revealed that high persistence of the aerosol layer is due to trapping of transported aerosols by the Tibetan anticyclonic circulation. A recent observational study revealed that high concentration of black carbon in the boundary layer inhibits the convective activities. Dual-frequency radar, on-board GPM, measurements of drop size revealed the predominance of low-level hydrometeor growth over oceanic region and Western Ghats and evaporation of smaller drops over dry regions of India. A medium scale global weather prediction system with 3-D En-Var assimilation system has been developed using MPAS, which demonstrated its capability in predicting tropical cyclone seven days in advance.

The Advanced Indian MST Radar (AIR), having an active phased array configuration with 360 azimuthal beam agility, higher sensitivity, modularity, multi-receiver capability and built-in scalability, facilitating new innovative experiments has been developed. A 9.3 GHz dual polarization Doppler weather radar with solid-state technology has been indigenously developed for understanding microphysical properties of precipitation and validating satellite-based precipitation estimates. A ground-based network consisting of NavIC and GNSS receivers has been established for imaging total electron content (TEC) in the ionosphere and integrated water vapor in the troposphere. A Peta-scale computing system has been established for weather and climate research.

A. MAJOR FACILITIES/INSTRUMENTATION DEVELOPED:

- **Advanced Indian MST Radar (AIR):** The Advanced Indian MST Radar (AIR), having an active phased array configuration and multiple receivers, has been established with 360 azimuthal beam agility, higher sensitivity, modularity, multi-receiver capability and built-in scalability, facilitating new innovative experiments. It consists of 1024 Solid-state Transmit/ Receive modules each feeding independently to 1024 antennae, a new RF distribution scheme facilitating selection of antenna modules and spacing required for various spaced antenna and interferometry/Imaging applications. Currently, 18 receivers are in place allowing multi-receiver experiments.

- **X-band Dual Polarization Doppler Weather Radar:** A state of the art 9.3 GHz dual polarization Doppler weather radar has been established at NARL for understanding microphysical properties of precipitation and evaluating satellite-based precipitation estimates. In addition to quantifying the precipitation rates accurately, the radar provides microphysical information of size, shape and phase of hydrometeors over a large area (80 km radius) around Gadanki. The scanning capability of the X-band radar augments the vertically pointing systems at NARL and opens up a new era of precipitation research.

- **Peta-scale High Performance Computing System:** A peta-scale computing system has been established for high-resolution modelling of weather phenomena, improving physical parameterization schemes, and climate research. A total computing power with CPU nodes of 1.418 PetaFLOPS and GPU nodes of 240 TFLOPS provide an overall peak performance of 1.658 PetaFLOPS. The system has 2 PB storage capacity with a throughput of 27GBps and an additional 250 TB storage with a throughput of 100 GBps. The HPC is supported by an uninterrupted power supply by redundant UPS and diesel generators and in-row cooling air conditioning system.

- **NavIC/GNSS Receiver network:** A ground-based network consisting of NavIC and GNSS receivers has been established for imaging total electron content (TEC) in the ionosphere and Integrated watervapor (IWV) in the troposphere. The dense network in southeast India is designed for watervapor applications, while the coarse network spread over the entire India is for ionospheric applications. The network is being augmented for high-resolution 3D mapping of watervapor and electron density using tomographic techniques.

B. SCIENCE RESULTS

- **IONOSPHERE, MAGNETOSPHERE AND SOLAR-TERRESTRIAL RELATIONSHIP:**

  - **150 km echoing phenomenon:** One of the outstanding problems of ionospheric research is the origin of 150-km echoes. Dual frequency observations carried out from NARL have clearly revealed that some of them are due to plasma instability, which adds to the prevailing proposal of photoelectron induced enhanced plasma wave causing these echoes. The cause of quasi-periodicity has also been addressed. Based on the current analysis it has been

suggested that AGW induced density variations can lead to enhanced photoelectron induced plasma processes and instability to account for most of the observed features of the 150-km echoing phenomenon.

- **Equatorial Plasma Bubble (EPB):** A multi-instrument study coupled with numerical simulation has been carried out to understand the role of gravity waves in triggering equatorial plasma bubbles (EPBs). This study reveals that along with gravity waves, density gradient and the height of F layer play an important role in the generation of plasma bubble. Based on a large data base, a forecasting scheme has been developed for the occurrence of EPB over Gadanki longitude.

- **Vertical Plasma Drift model:** An artificial neural network-based model has been developed for inferring ionospheric daytime vertical plasma drift using ground-based magnetometer observations in the Indian sector. The model results also show the equinoxial maxima and reveal year to year variability as observed in the seasonal and local time variations of the drift.

- **Space weather Impacts on TEC:** A robust analysis has been made consisting of 37 major and moderate geomagnetic storms addressing the response of daytime ionospheric total electron content during the main phase of the storms. Analysis shows that switching of polarity of prompt penetration electric field (directed east to west or vice versa) immediately affects the equatorial and low latitude vertical plasma drift as well as the total electron content. A study linked with 17-18 March 2015 geomagnetic storm shows unusual and large interhemispheric asymmetry in total electron content during the main phase of the storm. Various sources of the asymmetry like orientation of interplanetary magnetic field, field aligned currents and polar specific coupling efficiencies during different seasons are invoked to explain the observations.

- **Martian ionosphere:** In the Martian ionosphere, magnetically controlled density structures have been found to be influenced by atmospheric waves. It has been shown that density structures in magnetic anomaly regions can occur in the lower ionosphere as well (Figure 1). It has also been observed that thermospheric neutral density and temperature show a strong local time asymmetry. Also, during the dust storms while the altitude of the Martian ionosphere increases gradually in non-magnetic field regions, the increase is irregular in regions of strong magnetic fields.

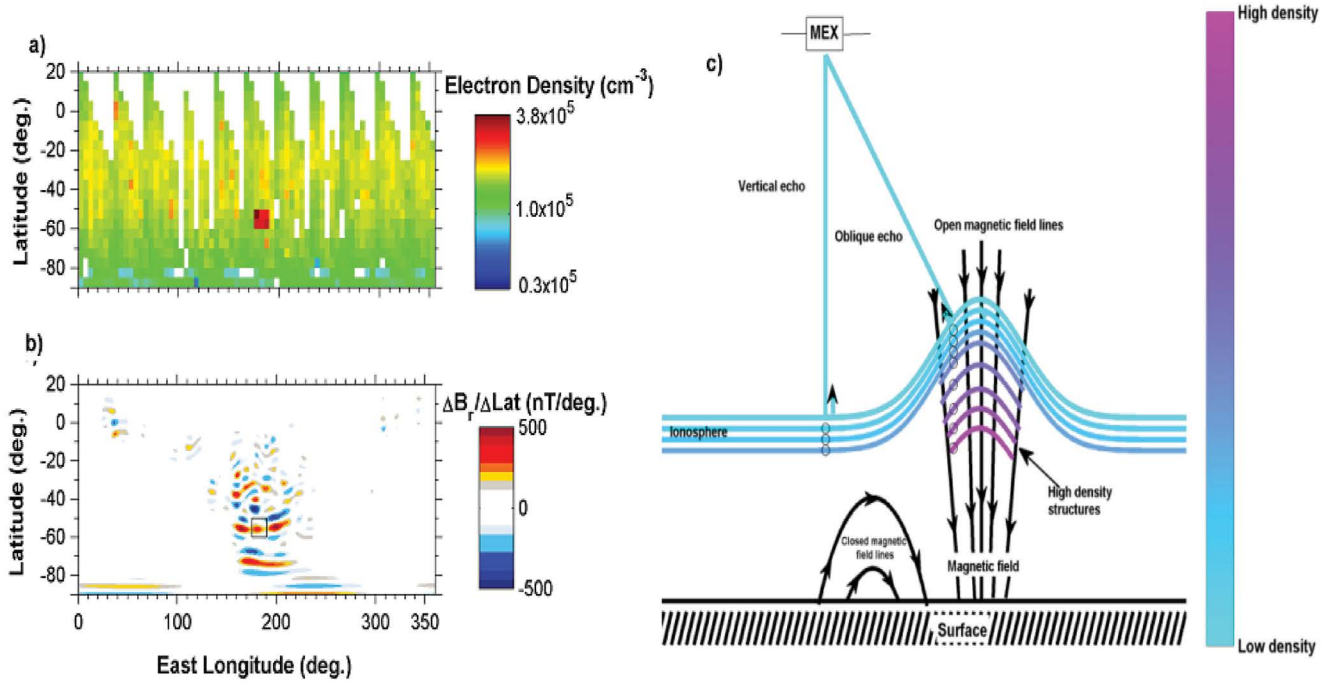

Fig 1: *Longitude-latitude contours of (a) electron densities corresponding to peak frequencies of vertical and merged echoes in MARSIS ionograms, (b) latitudinal gradients of the radial component of the magnetic field computed at an altitude of 100 km. The rectangle in Figure b shows the region of oblique echo observations. (c) A schematic depicting the density structures with background ionosphere and isolated high density structures without any background ionosphere*

- **EARTH'S ATMOSPHERE AND CLIMATE:**

  - **Trends in surface temperature:** The natural and external forcings responsible for Surface Temperature variability have been studied from CMIP5 models during the 20th century and projections during the 21st century along with seasonal variability. Temperature over India has increased by ~0.055 K/decade during 1860–2005 and follows the global warming trend. Greenhouse Gases (GHG) and Land Use (LU) are the major factors that gave rise to warming during the 20th century. Analysis of rare heat and cold events for 2080–2099 relative to a base period of 1986–2006 under RCP8.5 scenarios reveals that both are likely to increase substantially. However, by controlling the regional AA and LU change in India, a reduction in further warming over India region might be achieved.

  - **Asian Tropopause Aerosol Layer (ATAL):** As a part of ISRO-NASA BATAL campaigns, specialised experiments have been conducted to investigate the Asian Tropopause Aerosol Layer and their sources. The chemical transport modeling of ATAL using WRF-Chem has shown that the layer exists at 200 – 100 hPa in the model simulation. The model shows that ATAL is formed due to the trapping of transported chemical species to north India due to Tibetan Anticyclone. Model simulations have revealed that this layer is composed of sulphates

and nitrates in contrast to the observations which have shown that it is formed due to only nitrates.

- **Role of black carbon aerosol on atmospheric instability:** Recent studies have indicated invigoration of convection is due to the evolution of thermodynamic instability or cloud microphysics caused by aerosols. A detailed analysis revealed that high values of Black Carbon are often associated with weak convection. During the deep convection, however, such a simple relation between the concentration of black carbon and vigor of convection has not been found. These observations suggest that higher concentrations of Black Carbon affect the convective available potential energy in the atmosphere by perturbing the boundary layer temperature lapse rate profile.

- **Trend in Black Carbon:** Ten years (2008-2017) of Black Carbon (BC) observations obtained using Aethalometer are analysed to investigate the seasonal trends and temporal variabilities over Gadanki. Diurnal variations of BC have two peak structures one in the morning (~08 IST) in all seasons and second in the evening (~20 IST) only during the pre-monsoon (March-May). The inter-annual variability of BC did not show any significant trend. However, trends in the maximum (March) and minimum (July) BC values show statistically significant decreasing trend suggesting reduction in bio-mass burning sources during March supported by the decrease in the fire counts.

- **Enhancement in semi-diurnal tidal amplitude during SSW:** The reasons for enhancement of semi-diurnal tide during the sudden stratospheric warming (SSW) events have been investigated. It has been found that though migrating tidal amplitudes are larger at mesospheric heights, the non-migrating tidal amplitudes become comparable to those of migrating tides above 100 km and their contribution becomes increasingly important at higher heights. Besides, lunar tidal contribution is relatively less when compared to solar tides.

- **Global climatology of planetary boundary layer height:** The long-term climatology of global distribution of PBL is presented by using GPSRO based payloads. The derived PBL top from GPSRO data is rigorously evaluated with GPS radiosonde data over Gadanki. The global distribution of PBL top shows significant seasonal variation with higher values during summer followed by spring, fall, and minimum in winter (Figure 2).

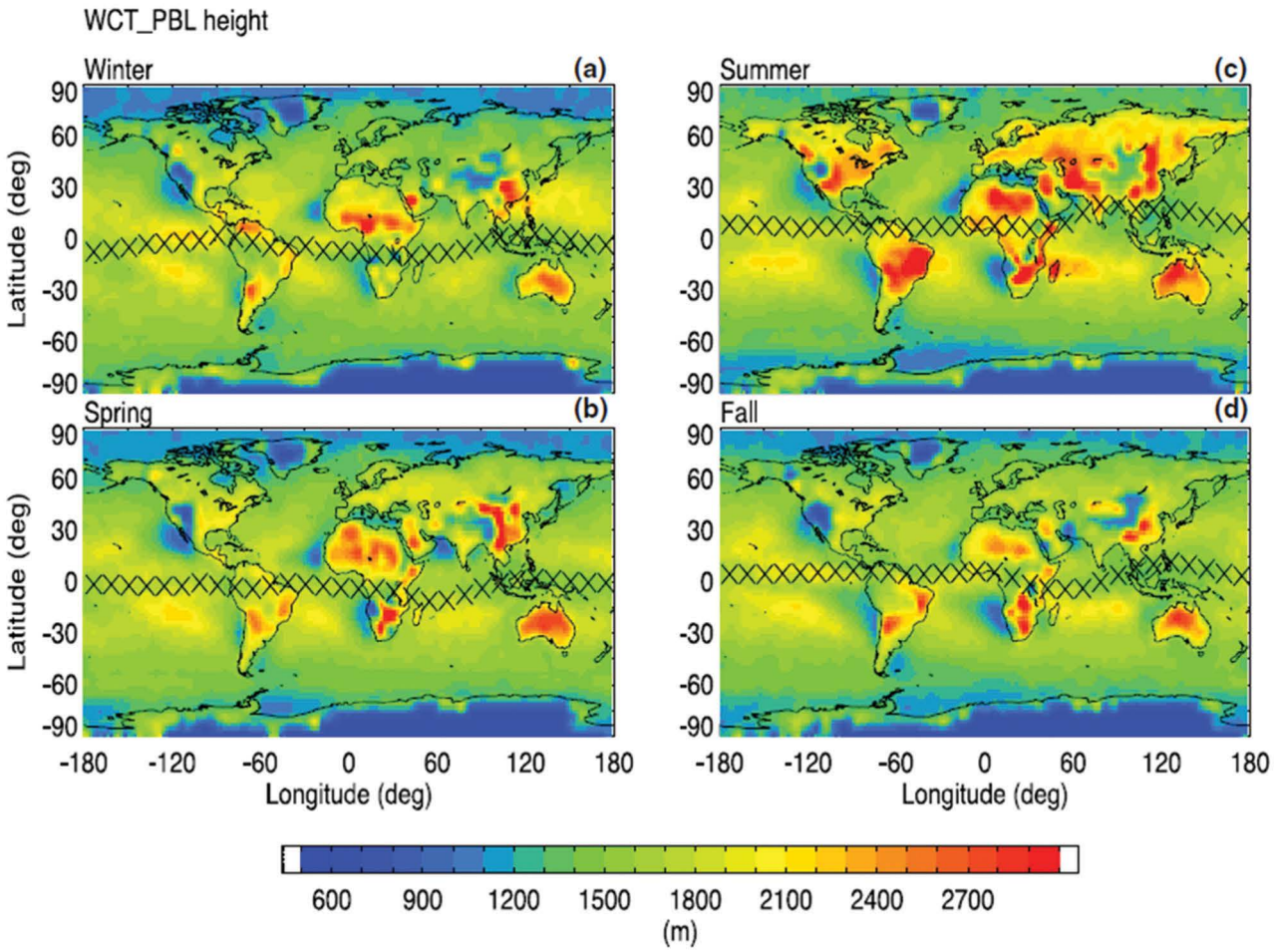

Fig 2*: Mean PBL top derived from GPSRO satellites for four different seasons gridded to a fine resolution of 0.5 × 0.5°. The location of ITCZ is marked with cross symbols.*

- **Raindrop Size in different climatic zones of India:** The dual-frequency precipitation radar, aboard the Global Precipitation Measurement, derived drop size measurements show distinct variations in different climatic zones of India and adjoining seas (Figure 3). It is found that the microphysical and dynamical processes during the descent of hydrometeors play a vital role in altering the drop size. For instance, predominance of smaller drops over oceanic regions and Western Ghats even during deep rain indicates that the hydrometeor growth is predominantly occurring at lower heights. Larger D_m values over dry regions indicate that the evaporation of smaller drops is significant in those regions.

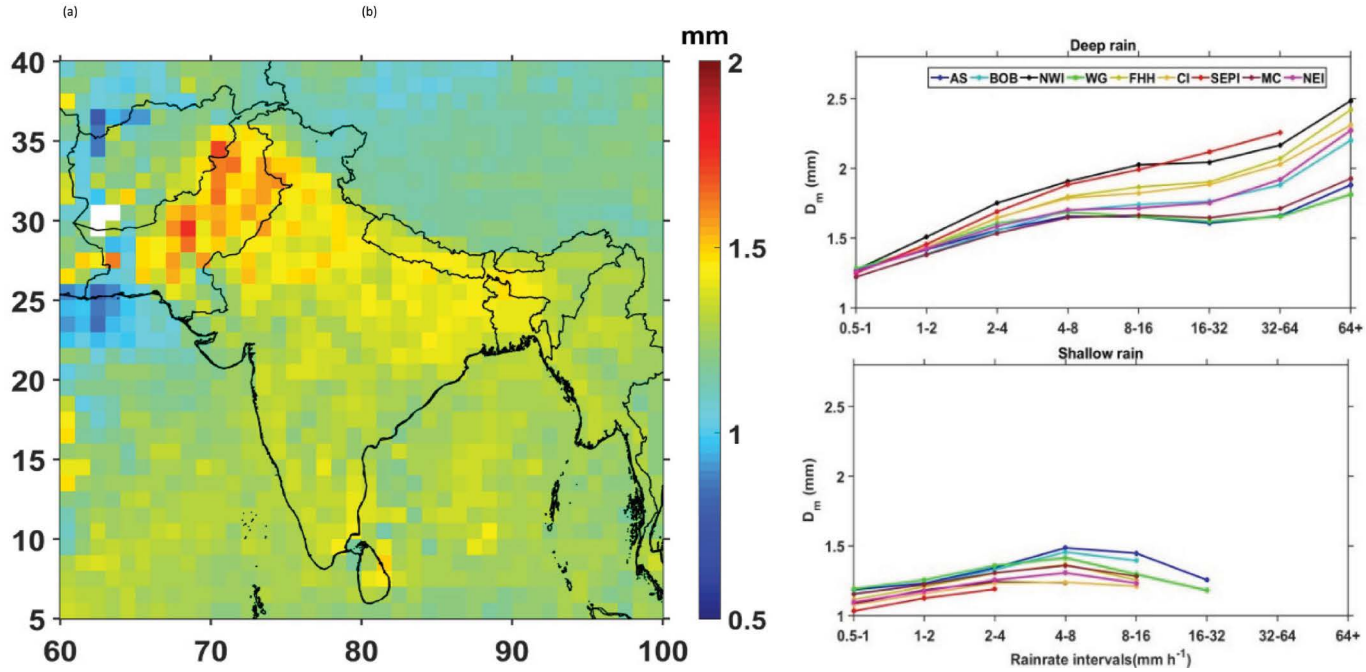

Fig 3: *(a) Spatial variation of near surface mean D_m (mm) over Indian sub-continent. (b) (Top panel) The D_m at different intervals of R obtained from GPM-DPR during the SWM season in the presence of deep precipitating systems at different climatic zones (AS – Arabian Sea; BOB – Bay of Bengal; NWI – Northwest India; WG – Western Ghats; FHH – Foot hills of Himalayas; CI – Central India; SEPI – Southeast peninsular India; MC – Myanmar coast; NEI – Northeast India). Bottom panel is same as top panel but for shallow precipitating systems.*

- **Spatial coherence of water vapor and rainfall:** Understanding the spatio-temporal variability of watervapor and its relation with rainfall is essential for weather and climate processes and also monsoon variability. Spatial patterns of coherency in atmospheric watervapor and rainfall correspond well over Indian sub-continent, but differ in magnitude (decorrelation distance) by a factor of 10, indicating that the rainfall homogeneity is generally limited. The stratiform rain occurrence is found to be high in regions of larger decorrelation distance.

- **Medium range weather prediction using MPAS forecast system:** A medium scale global weather prediction system has been established using multiscale model MPAS (Model for Prediction Across Scales). The model has shown very good skill in predicting the evolution of the atmosphere up to 7 days, including the evolution of deep convective events like tropical cyclone Mekunu.

- **Rapid cyclogenesis of Extremely Severe Cyclonic Storm Hudhud (2014):** The study on rapid intensification of tropical cyclone has suggested that the distribution of deep convection in the positive helicity region accelerates the genesis sequence causing rapid intensification of tropical cyclones.

- **Sensitivity of boundary layer and microphysics schemes on Extreme Heavy Rainfall Event over Chennai, India using WRF:** On 01 December 2015, Chennai, the capital city of Tamil Nadu state in the southeast coast of India received unprecedented rainfall of about 490 mm. The sensitivity of boundary layer physics and microphysics schemes of WRF have been tested in resolving the location of intense rainfall and its distribution. The study revealed that explicit microphysics at 1 km resolution and MYNN-TKE planetary boundary layer schemes improve the prediction of timing and intensity of storm and distribution of rainfall.

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SPACE PHYSICS LABORATORY, VSSC

Thiruvananthapuram

Space Physics Laboratory (SPL), Vikram Sarabhai Space Centre (VSSC) is committed for research in different disciplines of atmospheric, space, and planetary sciences. Apart from being involved in ISRO's science missions such as Chandrayaan-1 & 2, Mars Mission, Megha-tropiques etc., it is involved in research in the specialised areas of space and atmospheric science. SPL also coordinates programs of national/international importance like the ISRO-Geosphere Biosphere Programme, etc. while initiating programs in the important area of Space Weather. The research community of SPL conducts major experimental campaigns, at national and international level, using balloons, air crafts, rockets, and research ship cruises from time to time.

A. MAJOR RESEARCH

1. Remote sensing of Earth's resources and environment

- **On the Role of Precipitation Latent Heating in Modulating the Strength and Width of the Hadley Circulation**

The present study quantified the influence of Latent Heat (LH) release on the spatial extent and intensity of the Hadley Circulation (HC) using the vertical profiles of LH derived from 16 years of space based observations of TRMM PR as well as from MSF derived from the ERA-I reanalysis data. The current study thus provided evidence for the results of these modelling simulations on how the HC is influenced by the LH release (Figure 1). The spatial distribution of the LH derived from the TRMM observations showed features of tropical convective activity consistent with the present knowledge, thus providing the credence for the TRMM LH measurements.

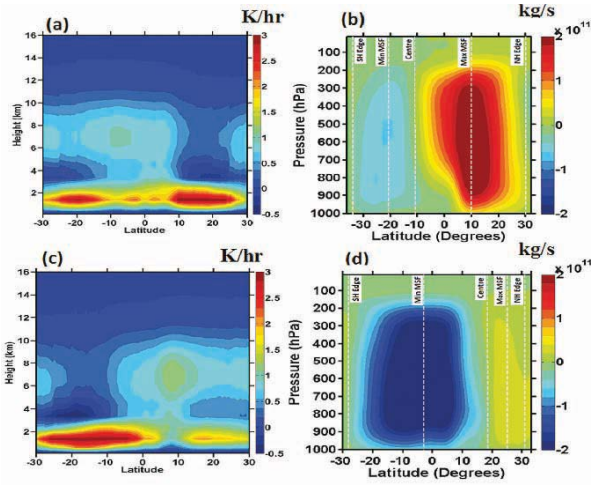


Fig 1: *The latitude-height section of zonal mean LH over the tropics estimated from the TRMM PR measurements during the period 1998-2013 for (a) DJF (c) JJA. Also, vertical cross-section of MSF estimated from ERA-I reanalysis data during the period 1998- 2013 for (b) DJF (d) JJA. The HC boundaries are marked by dashed lines in (b) and (d).*

- **Vertical profile of methane over the Indian region: impact of synoptic scale meteorology**

Seasonal variations in the vertical profile of CH_4 have been studied over the Indian region based on the satellite-borne Atmospheric Infrared Sounder (AIRS) derived CH_4 mixing ratios (1°×1° gridded data). Prior to the analysis, an inter-comparison between in-situ measurements by CARIBIC (Civil Aircraft for the Regular Investigation of the atmosphere based on an Instrument Container) aircraft data and AIRS retrieval is carried out. After filtering the CH_4 retrievals of AIRS for the cloud fraction greater than 0.25, CH_4 interpolated for the latitude, longitude and pressure levels corresponding to the location of in-situ measurements. Figure. 2, shows the inter-comparison between co-located (in terms of space and time) in-situ measured CH4 by CARIBIC and AIRS retrieved CH4 in the upper-troposphere (300–150 hPa) during 2008. This shows the AIRS could capture the broader (monthly or seasonal scale) variations well. The inter-comparison is limited to the upper-tropospheric CH4. The monthly mean upper-tropospheric CH4 averaged over three latitude sectors over the Indian region (68–82° E) during 2008 for CARIBIC and AIRS show more or less similar annual variations in the upper-tropospheric CH4 in all the three latitude sectors with differences in the monthly amplitudes.

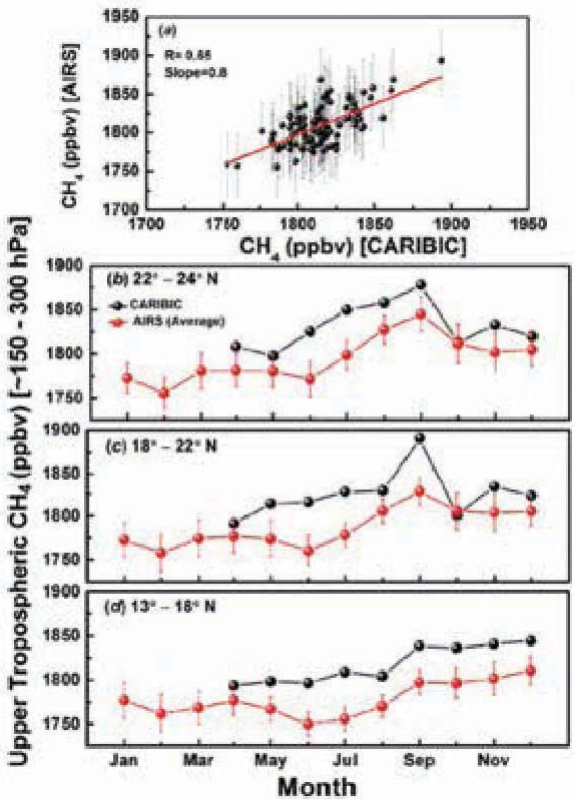


Fig 2: *(a) Scatter plot between in-situ measured CH4 by CARIBIC and co-located AIRS retrieved CH4 in the upper-troposphere (300–150 hPa) during 2008. The error bar shows the error in the CH4 retrievals by AIRS. (b–d) Monthly variation of upper-tropospheric CH4 retrieved by CARIBIC and AIRS averaged over three latitude sectors over Indian region (68–82° E) during 2008.*

- **Three dimensional distribution and trend in mineral dust over India: Results from CALIOP and AERONET observations**

The westerlies prevailing during the pre-monsoon and summer monsoon season over the Indian region are conducive for the transport of dust aerosols from West Asia. The space-borne lidar Cloud Aerosol Lidar with Orthogonal Polarization (CALIOP) on board Cloud Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO), measure polarization resolved backscattered radiation enabling the quantification of dust aerosols. The spatial distribution of dust optical depth at 532 nm during pre-monsoon over South Asia, estimated using CALIOP observations of aerosol backscattering coefficient and depolarization ratio is shown in Fig.3(a). High values of dust optical depth (~0.5) are observed over the major source regions such as West Asia, Thar, and Taklamakan deserts. The vertical extent and magnitude of lower free tropospheric dust extinction coefficient increase from winter to pre- monsoon. A prominent elevated aerosol layer above the planetary boundary layer (Fig.3b) is formed as a result of transport.

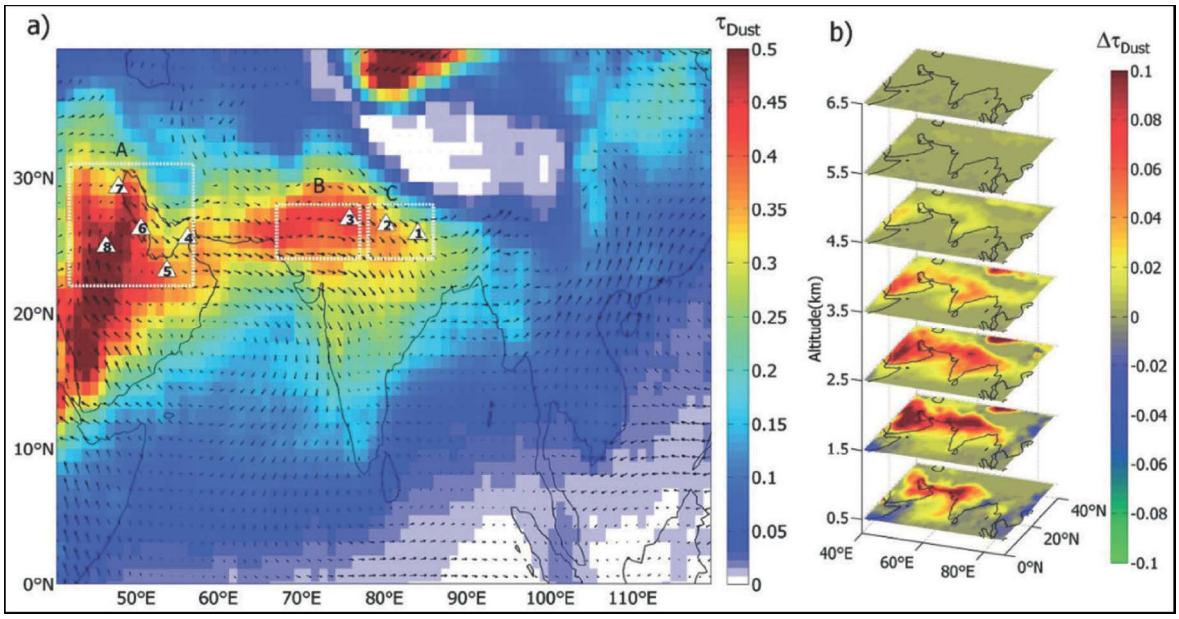


Fig 3: *(a) Spatial distribution of dust optical depth over the Indian region during pre-monsoon (March–May) season. Vector winds are at 850 hPa and AERONET radiometer stations (1. Gandhi College, 2. Kanpur, 3. Jaipur, 4. Dhadnah, 5. Mezaira, 6. Bahrain, 7. Kuwait University, and 8. Solar Village) are shown with triangle symbol. The three regions representing (i) West Asia, (ii) Northwest India, and (iii) IGP are shown in boxes. (b) Vertically resolved spatial map of the difference in dust optical depth from winter and pre-monsoon to show the vertical distribution of pre-monsoon enhancement in dust over the study regions.*

- **The trend in mineral dust over India: Results from CALIOP and AERONET observations**

The inter-annual variation of dust AOD depth (dust AOD) derived from CALIOP and coarse mode AOD (AOD at 1020 nm) from AERONET stations over IGP, Northwest India, and West Asia during pre-monsoon season is shown in Fig.4. The inter-annual variations and long-term trends in dust

AOD over South Asia are distinctly different to that over West Asia. Within South Asia, inter-annual variation in dust AOD over IGP and Northwest India shows a similar pattern which suggests that dust emission from the Thar Desert is contributing significantly to the dust loading over IGP. The inter-annual variation of pre-monsoon dust AOD over the Indian region shows an oscillatory pattern during 2007–2013 with a decreasing trend, which is supported by the long-term variation in coarse mode AOD (mostly contributed by dust) estimated from the ground based AERONET observations. The inter-annual oscillations in pre-monsoon dust optical depth over Northwest India is found to be negatively associated with winter time rainfall. However, the decreasing trend in dust loading over the Indian region reversed to increasing after 2013 with a drastic change in the oscillatory pattern of the inter-annual variation in dust AOD.

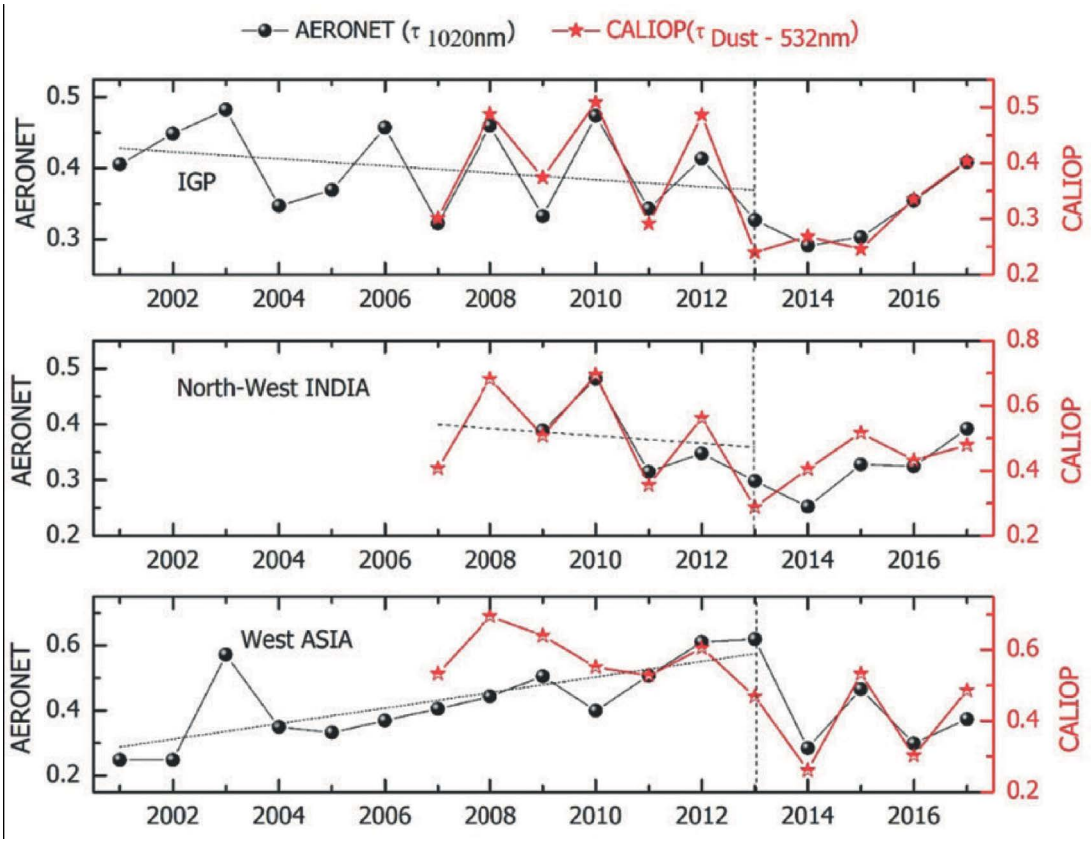


Fig 4: *Inter-annual variation of dust AOD during pre-monsoon season (March–May) retrieved from CALIOP and total coarse mode AOD from AERONET stations, are shown for (a) IGP, (b) Northwest India, and (c) West Asia. Black dashed lines show linear fits to the data up to 2013 and black vertical dashed lines indicate the end of the slowdown in dust activity*

2. Earth's Atmosphere and Climate

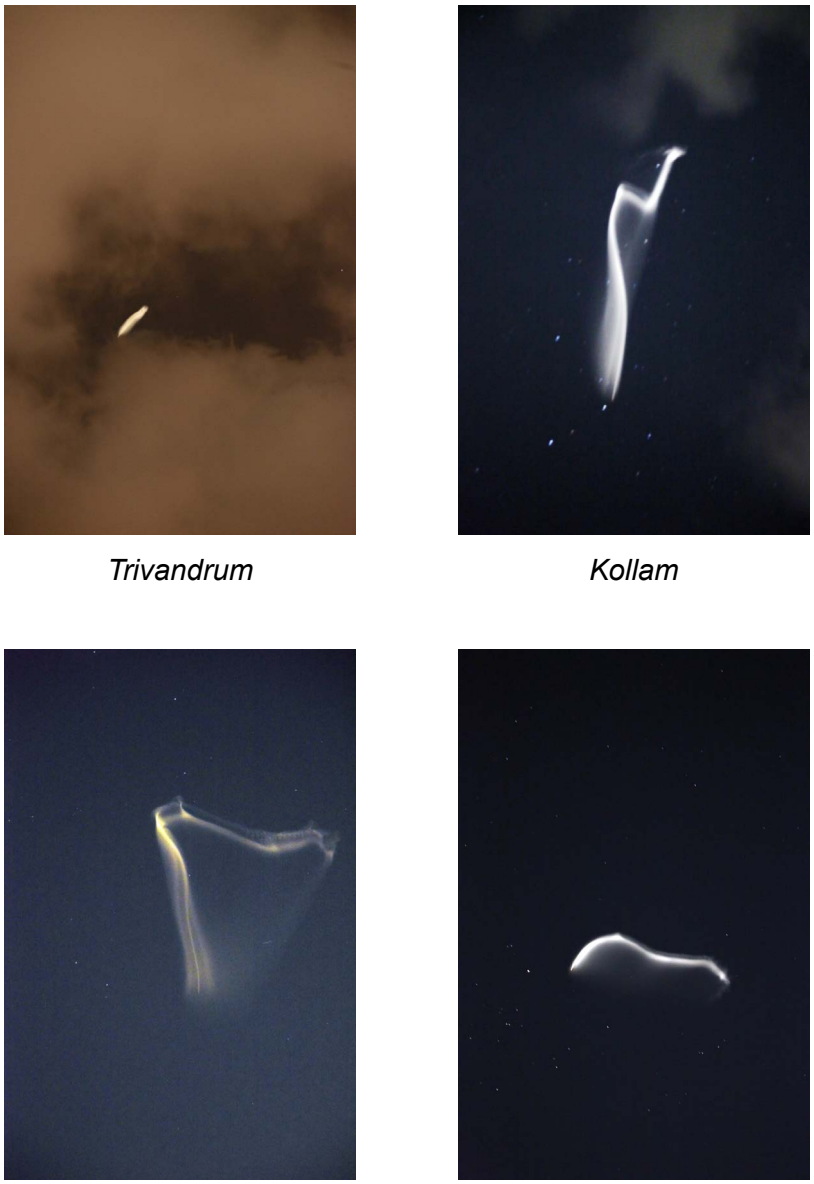
- **SOUnding Rocket Experiment (SOUREX) for Upper Atmospheric Studies over Geomagnetic Equator**

The first flight of the SOUREX series was conducted using RH 300 MkIII from Thumba Equatorial Rocket Launching Station (TERLS) on April 06, 2018, which carried three scientific payloads

namely (i) Electron density & Neutral Wind (ENWi) Probe, (ii) Langmuir Probe (LP) and (iii) Trimethyl Aluminium (TMA) vapour release. The prime scientific objectives of this scientific campaign have been (i) to measure the ionospheric density and neutral winds in the E-Region (~90-120 km) of the ionosphere using two independent techniques namely ENWi and TMA vapour release, (ii) to cross validate the measurements of wind by these techniques, (iii) To investigate the modulations in the neutral wind along with electron density at dynamo heights and their implications in providing a trigger for the generation of equatorial Plasma Bubble. There have been gaps in our comprehension of equatorial ionosphere, especially in 90-120 km altitude region, mainly for the want of simultaneous neutral and plasma measurements, and a suitable technique.

To address to this need of simultaneous neutral and plasma measurements, a novel probe ENWi i.e. Electron Density and Neutral Wind Probe method was developed in house for in situ measurements at the desired ionospheric altitudes. The versatility of this probe is effectively enhanced by adding another spherical sensor LP (Langmuir Probe) for electron density and irregularity measurements also.

The SOUREX flight reached an apogee of about 108 km in 160 seconds. The TMA vapor was successfully released between 90 to 108 km and imaged from three pre-identified locations namely Kollam, Kanyakumari and Tirunelveli. As obtaining the wind profiles from the TMA trails requires observations of the luminous trails from at least three spatially-separated, ground-based camera sites. A triangulation was then carried out to determine the velocity at each altitude. The data showed presence of plasma enhancements associated with Equatorial Electrojet in the ENWi and LP data. The observations involving TMA are first of its kind in India and warrant special attention. The TMA trails clearly indicated presence of strong wind shears and waves in the region 90-105 km, which have significant manifestation on the generation of E and F-region plasma irregularities. The preliminary estimate of the wind as obtained through ENWi agree with that obtained using the TMA technique within ± 20m/s. In brief, the SOUREX Phase-I experiment with RH 300 Mk-II launch on April 06, 2018 has been scientifically successful.



Trivandrum *Kollam*

Tirunelveli *Kanyakumari*

Fig 5: *TMA trail from four ground stations*

- **Characterization of the long-term changes in moisture, clouds and precipitation in the ascending and descending branches of the Hadley Circulation**

The Hadley Circulation (HC) is a tropical circulation that is driven by the differential heating of the Earth's surface by solar radiation. The tropical regions which fall under the ascending branches of HC are characterized by a wet climate, whereas the subtropical regions under the descending branches of the HC are either arid or semi-arid. Any change in the intensity or width of the HC will have paramount effects on the climate of the regions under the ascending and descending branches of the HC. Climate model simulations and observations show that there is a poleward expansion of the HC as well as a strengthening of the hydrological cycle in a warming climate. In

this regard, the present study employs relative humidity (RH), cloud fraction (CF) and precipitation (RF) parameters of the hydrological cycle and analyse their long term changes within the HC ascending and descending regions, simultaneously. Long term RH and CF data (1979-2016) are obtained from ERA-I reanalysis, and RF from GPCP precipitation dataset. The boundaries of the HC are identified using the mass Meridional Stream Function (MSF) metric, a metric that can track the mass motion in the atmosphere in the meridional direction. Fig. 6 gives a holistic view of the annual cycle of the various boundaries of the HC obtained from the zonal mean MSF metric.

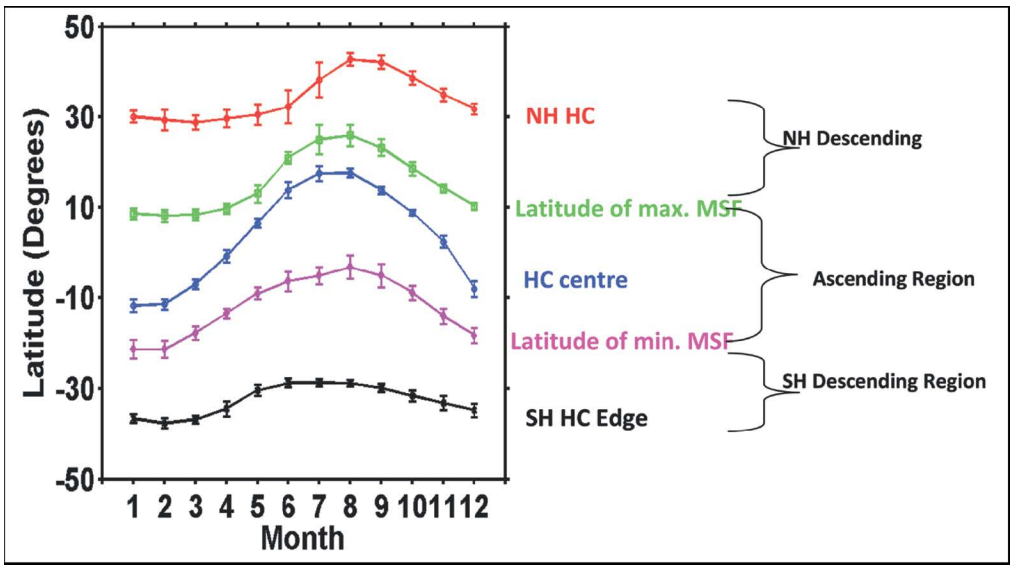


Fig 6: *Annual cycle of the HC centre, HC edges and the NH (SH) cell centres. Vertical bars indicate the standard deviation corresponding to their inter-annual variability. HC ascending regions are defined as the region between the latitude of maximum MSF and the latitude of minimum MSF. HC descending regions are defined as the regions between the latitude of maximum (minimum) MSF and the NH (SH) HC edge.*

- **High altitude Black Carbon Emissions: Possible climate implications**

The altitude distribution of BC in the atmosphere plays a crucial role in deciding the BC-induced warming of the atmosphere. Such an atmospheric warming due to BC is amplified when BC is above strongly reflective surfaces like clouds, can give rise to local instability and subsequent vertical lifting. Such absorption-warming-convection cycle can transport BC to higher altitudes. On account of its absorbing nature, high-altitude BC can burn off cirrus clouds. Realising the importance of the vertical profile of BC, high-altitude balloon borne measurements of BC were carried out on 17 March 2010, 8 January 2011 and 25 April 2011 from Hyderabad. The present study is a revisit to these three high-altitude balloon measurements to investigate the potential causes behind the existence of such confined BC layers using a regional chemistry transport model (WRF-Chem) simulations (Fig. 7). The present study demonstrates that high-flying aircraft (with emissions from the regionally fine-tuned MACCity inventory) are the most likely cause of these elevated BC layers. The observational evidence for an intrusion of tropospheric BC into the stratosphere over the Indian region is shown using extinction coefficient and particle

depolarisation ratio data from CALIOP Lidar on-board the CALIPSO satellite. It is hypothesised that such intrusions of BC into the lower stratosphere and its consequent longer residence time in the stratosphere have significant implications for stratospheric ozone, especially considering the already reported ozone-depleting potential of BC.

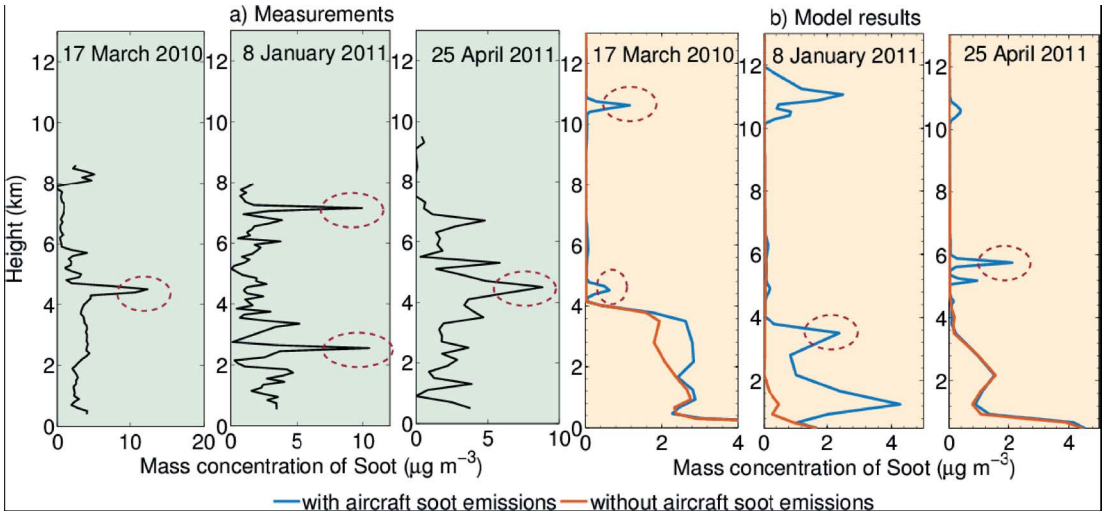


Fig 7: *Vertical variation of soot at various heights in the atmosphere as pointed out by a). high-altitude balloon measurements and b). Results of numerical model simulation, for 3 different balloon flight days. The sharp layers of soot at elevated heights are marked by a dotted red ellipse. The model simulations have been carried out in multiple configurations i.e. by including (blue line, panel b i.e. with aircraft soot emissions) and neglecting (orange line, panel b i.e. without aircraft soot emissions) soot emissions from aircraft*

- **Assessment of 1D and 3D model simulated radiation flux based on surface measurements and estimation of aerosol forcing and their climatological aspects**

Modeling the solar radiation and accurate estimation of the surface reaching fluxes is challenging. Ground reaching solar radiation flux was simulated using a 1-dimensional radiative transfer (SBDART) and a 3- dimensional regional climate (RegCM 4.4) model and their seasonality against simultaneous surface measurements carried out using a CNR4 net Radiometer over a sub-Himalayan foothill site of southeast Asia was assessed for the period from March 2013 - January 2015. The model simulated incoming fluxes showed a very good correlation with the measured values with correlation coefficient R2 ~ 0.97. Collocated measurements of the optical parameters of aerosols indicated a reduction in atmospheric transmission path by ~ 20% due to aerosol load in the atmosphere when compared with the aerosol free atmospheric condition. A climatological estimation of ARF is made over the study region for the period June 2008 to November 2014 and presented in Fig. 8. Estimation of aerosol radiative forcing efficiency (ARFE) indicated that the presence of black carbon (BC, 10 – 15%) led to a surface dimming by − 26.14 W m−2 τ−1 and a potential atmospheric forcing of + 43.04 W m−2 τ−1. BC alone is responsible for > 70% infl uence with a major role in building up of forcing efficiency. About ~ 3/4 of the radiation absorption in the atmosphere is ascribed to the presence of BC. Comparison of the satellite (MODIS) derived and ground based estimates of surface albedo showed seasonal difference in their magnitudes (R2 ~

0.98 during retreating monsoon and winter; ~ 0.65 during pre-monsoon and monsoon), indicating that the reliability of the satellite data for aerosol radiative forcing estimation is more during the retreating and winter seasons.

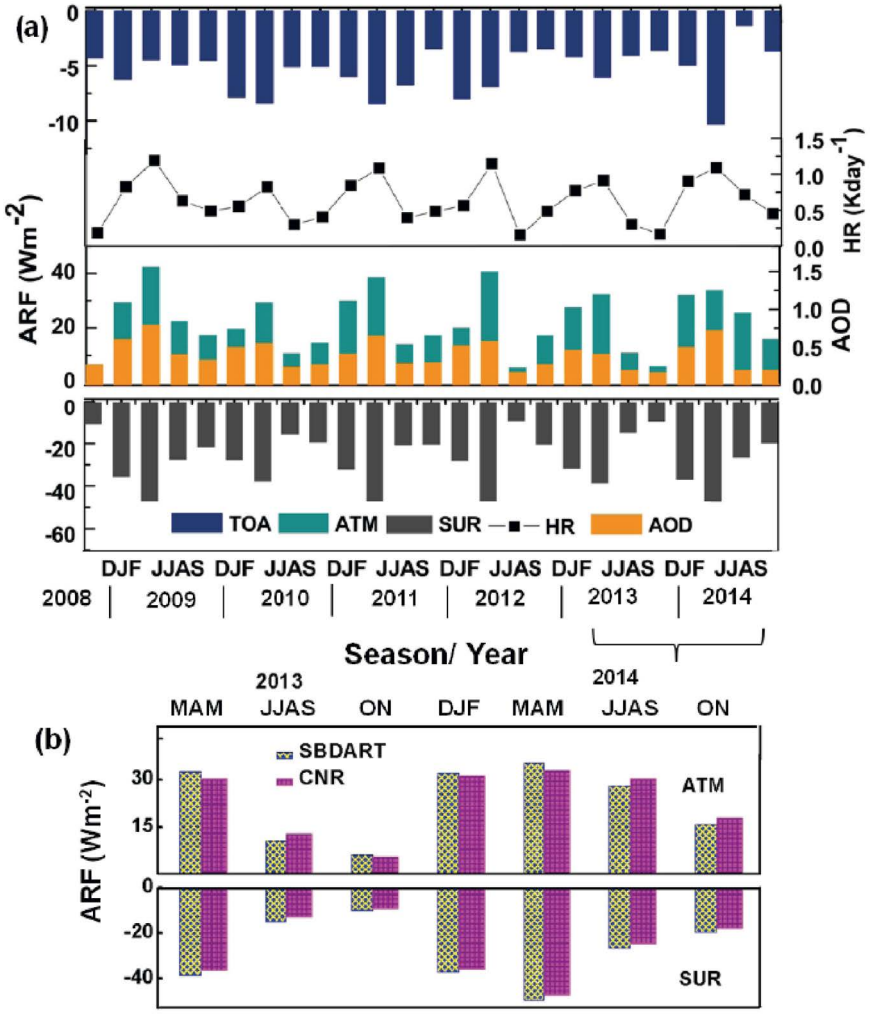


Fig 8: *(a) Seasonal SW aerosol radiative forcing at the top of the atmosphere (ARFTOA), in the atmosphere (ARFATM) and at the surface (ARFSUR) over Dibrugarh during the period JJAS 2008- ON 2014 along with the atmospheric heating rate (fi rst panel) and the AOD (500nm) variation (second panel) (b) Comparison of the seasonal SW aerosol radiative forcing estimation between model and ground based measurements in the atmosphere and at the surface over Dibrugarh from MAM 2013 - ON 2014.*

3. Ionosphere, Magnetosphere, and Solar – Terrestrial Relationship

- **The role of Thermosphere Ionosphere coupling in the generation of Post noon F3 layers over Thiruvananthapuram: A new perspective**

F3 layers are additional stratifications occurring above the F2 region peak. Occurrence of post noon F3 layers(beyond 13 IST) over Thiruvananthapuram (8.5°N; 77°E; dip latitude ~ 1.5 °N), a dip equatorial station in India have been investigated using ground based ionosonde, for the years

2004-2008. The present study attempts to explore whether the pre noon and post noon F3 layers can be explained on the basis of the same coupling processes as highlighted by Mridula and Pant (2015) and if so, whether all these processes are consistent with the overall understanding of the Thermosphere Ionosphere system. The occurrence of F3 layers were inferred from ionograms on a daily basis. Fig 9 (panels a to e) depicts the time of post noon F3 occurrence as inferred from the ionograms, along with the time of peak CEJ over Thiruvananthapuram for the period 2004 to 2008. During 2008, however, in addition to the usual high F3 layer occurrence during January and February, there is an enhanced occurrence during the July and August period also, which is unique to this year. It is found that the time of the ionospheric E- region electric field reversal as inferred from collocated ground based magnetometer observations plays a crucial role in the generation of post noon F3 layers. In fact an early reversal of electric field emerged to be the necessary condition for the formation of post noon F3 layers. A time delay of three to four hours is observed between the electric field reversal and the formation of F3 layer.

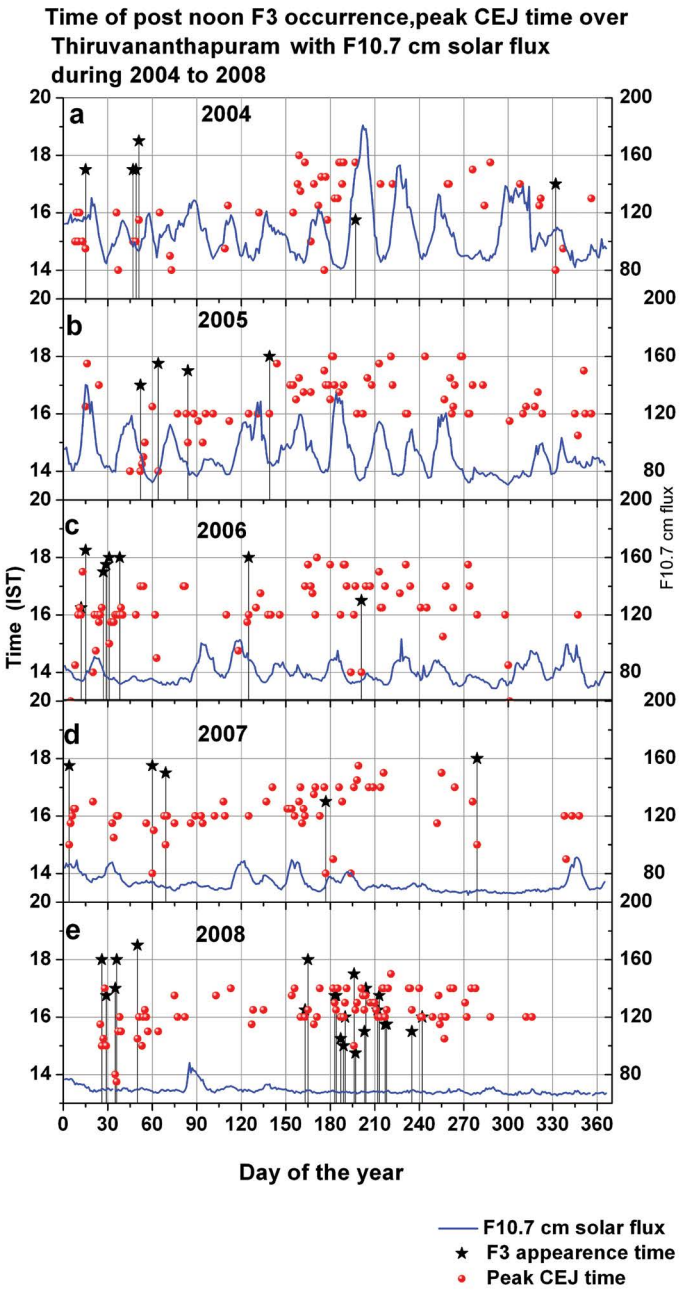


Fig 9: *Depicts the post noon F3 occurrence time, peak CEJ time and the F10.7 cm solar flux values for the period 2004 to 2008*

- **Climatology of GW-TIDs in the magnetic equatorial upper thermosphere over India**

Gravity waves (GWs) are buoyancy waves, in which gravity acts as the restoring force. They can propagate vertically and horizontally, transporting momentum from their source to their sink. Their periods correspond to several minutes to hours. It has been reported that the only factor that modulates ESF occurrence in the electrodynamic regime other than electric field is the GW induced seed perturbation. An analysis of Gravity wave induced travelling ionospheric disturbances (GW-TIDs) in the thermosphere during high and low solar epochs is undertaken

using ionosonde data at Trivandrum (8.5^{0}N, 77^{0}E). Wavelet analysis is performed on the temporal variations of foF$_2$ and the amplitude of waves present in two period bands of (0.5-1.5) h and (2-4) h are extracted. The real height profiles are generated at 15 min internal for the whole day (for sample days) during high and low solar activity years. The increase in amplitude of the waves of different periodicities as the altitude increases is evident from Fig.10. Fig.10 depicts the wave amplitude of the (2-4) h wave for the altitudes of 278 km (top panel) and 210 km (bottom panel). It is clear that the amplitudes are increasing with altitude and the phases of the wave are moving downward. This demonstrates the features of upward amplitude propagation and downward phase propagation, which confirm perturbations as of GW origin.

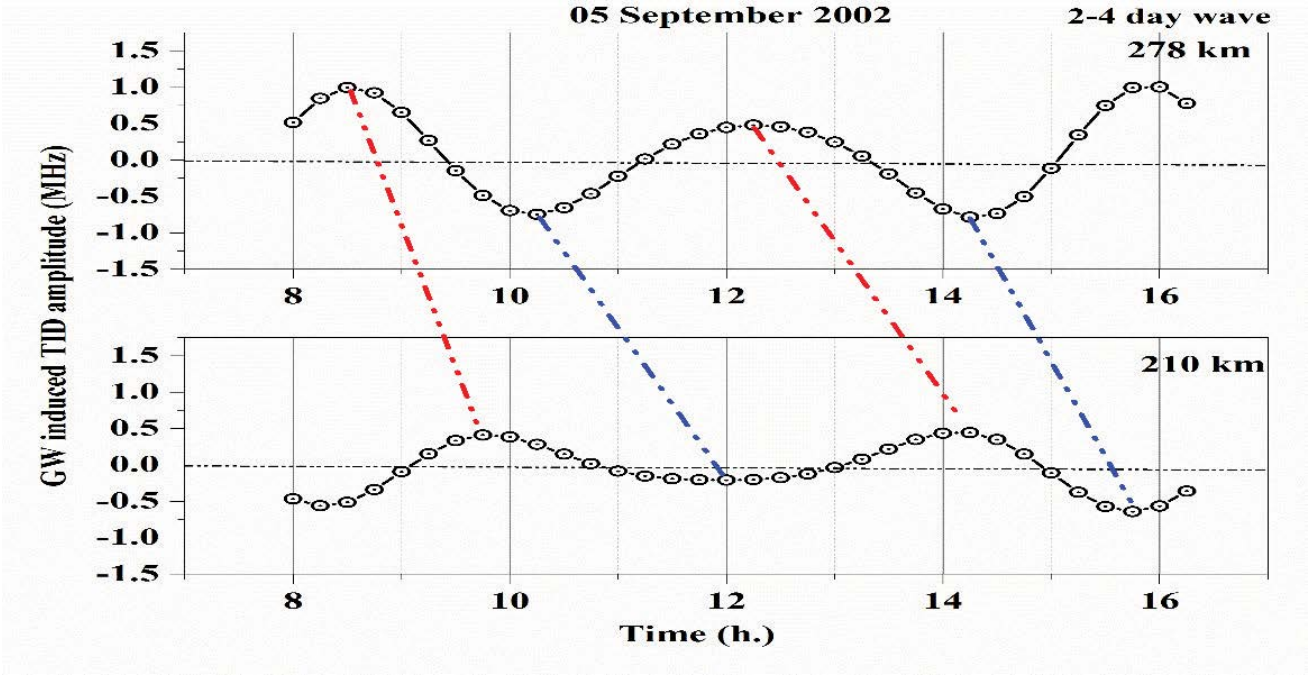


Fig 10:- *The wave amplitude of the (2-4) h wave for the altitudes of 278 km (top panel) and 210 km (bottom panel)*

- **Impact of Stratospheric Sudden Warming on the Occurrence of the Equatorial Spread-F**

This study presents the evidence for the Planetary Waves induced modulations in the start time of the Equatorial Spread-F (ESF) during the period when Stratospheric Sudden Warming (SSW) events occur.The analysis based on three years of data over Trivandrum (8.5^o N, 77^o E, 0.5^o N dip lat.), which include two SSW years and a non-SSW year, revealed that the PWs influence the start time of the ESF to a significant extent during the SSW years (Fig. 11). It has been observed that the PWs propagate to ionospheric dynamo region from the atmosphere below and modify the electrodynamic processes like the Equatorial Electrojet and Pre-Reversal Enhancement, which is more pronounced during the SSW years. Such a modification in the electrodynamics can modulate the equatorial plasma fountain and influence the F-region neutral dynamics, which in turn can affect the occurrence of ESF.

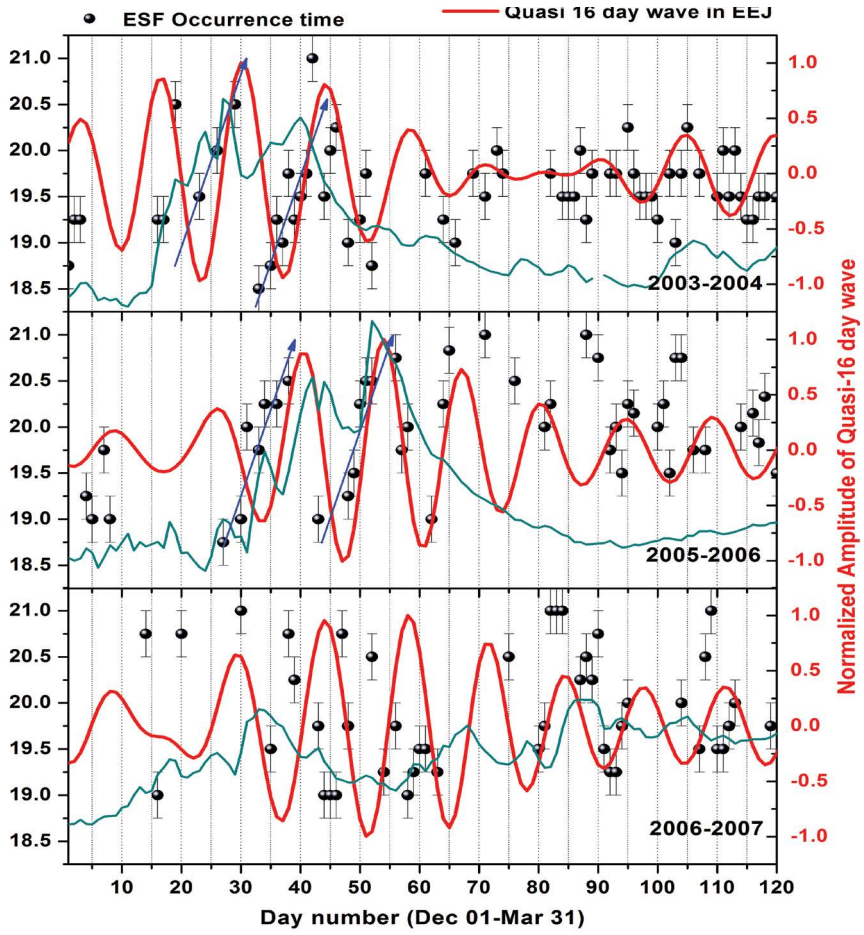


Fig 11:- *Day-to-day variation of time of occurrence of ESF (black circles) along with the amplitude of dominant PW in peaking time of EEJ (red) during the periods 2003–2004, 2005–2006, and 2006–2007. The green line shows the daily variation of polar stratospheric temperature at 10 hPa. The blue arrows represent the systematic shifting of occurrence time of ESF toward later night*

- **Morphological study on the ionospheric variability at Bharti, a polar cusp station in the southern hemisphere**

The morphology of the variations in the TEC during magnetically quiet as well as during geomagnetic storm periods in the polar cusp region of the Earth's ionosphere has been investigated using measurements of the TEC by a dual frequency GPS receiver installed at Indian Antarctica Station, Bharti. The position of Bharti with respect to the auroral oval and the quiet time convection pattern is shown in Fig.12. During magnetically quiet times, Bharati is located in the polar cusp region at magnetic noon, inside the polar cap at night, and in the auroral region twice a day. Such a dynamic nature of the position of Bharti with respect to the polar cap, makes it ideal to study the response of space weather events on the Earth's ionospheric system. Monthly variations in the TEC over Bharti during 2013 – 2017, and their comparison with the IRI-2016 model are shown in Fig.12.

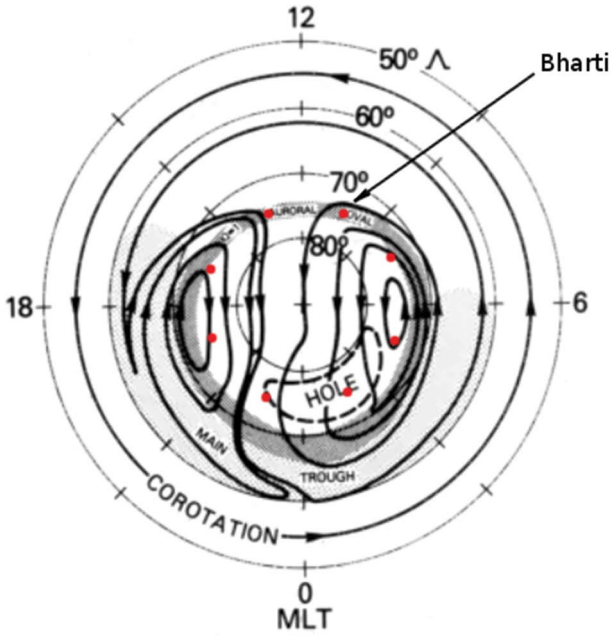


Fig 12:- *Approximate location of Bharti (shown using red dots) with respect to the plasma convection, the quiet time auroral oval, the main trough and the polar hole. The Local time (LT) = Magnetic Local Time (MLT) + 3 h at Bharti*

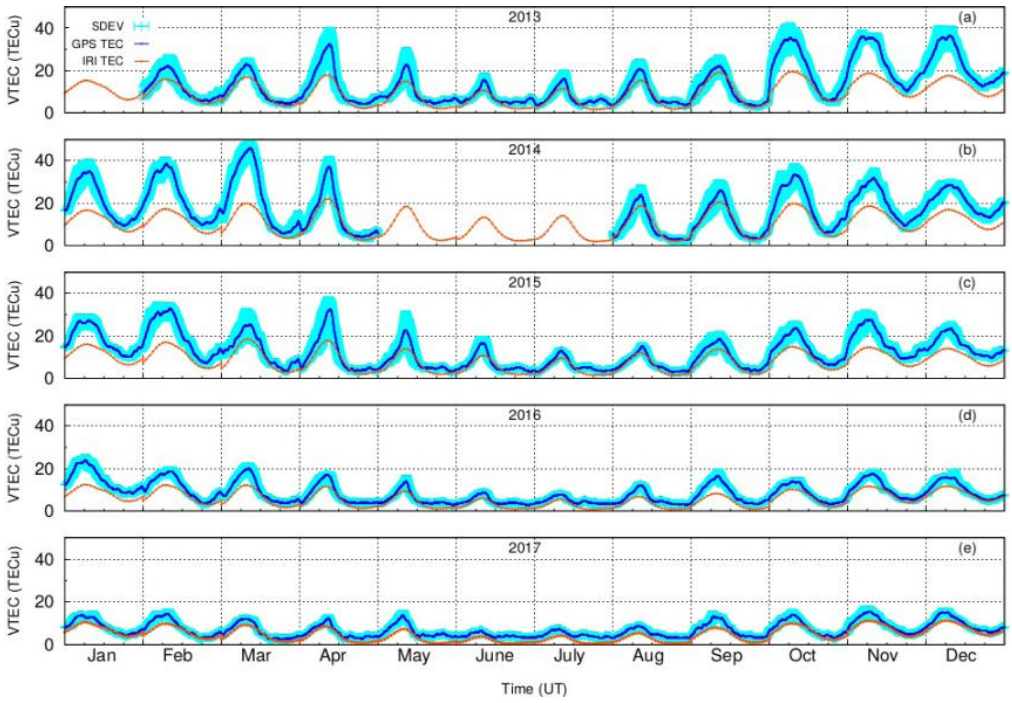


Fig 13:- *Variations in the TEC at Bharati during the years 2013–2017. The GPS TEC is represented by blue color and is shown along with the standard deviation shown in cyan. The IRI TEC is represented by orange color*

4. Solar System Bodies, including Planetary Science

- **A Photochemical Model for the dayside ionosphere of Mars.**

In the present study a one dimensional photochemical model for the dayside ionosphere of Mars has been developed for calculating the density profiles of ions and electrons under steady state photochemical equilibrium condition. Presently, the Mars Atmosphere and Volatile Evolution Mission (MAVEN) is providing in-situ composition measurements and unprecedented data on Martian thermosphere and ionosphere. The model simulated the conditions that prevailed on Mars during the deep dip (DD) campaigns of MAVEN. The modelled ion profiles are compared with the ion mode observations of Neutral Gas Ion Mass Spectrometer (NGIMS) and electron density estimates from Langmuir Probe and Waves (LPW). The model could very well reproduce the observed profiles of the ions O^+, C^+, and N^+ using the actual NGIMS-CO_2 density without applying any scaling factor. Therefore, the simulations cannot conclusively confirm that the neutral CO_2 densities are exactly off by a factor of four, but only indicate a possibility of overestimation in the NGIMS-CO_2 density.

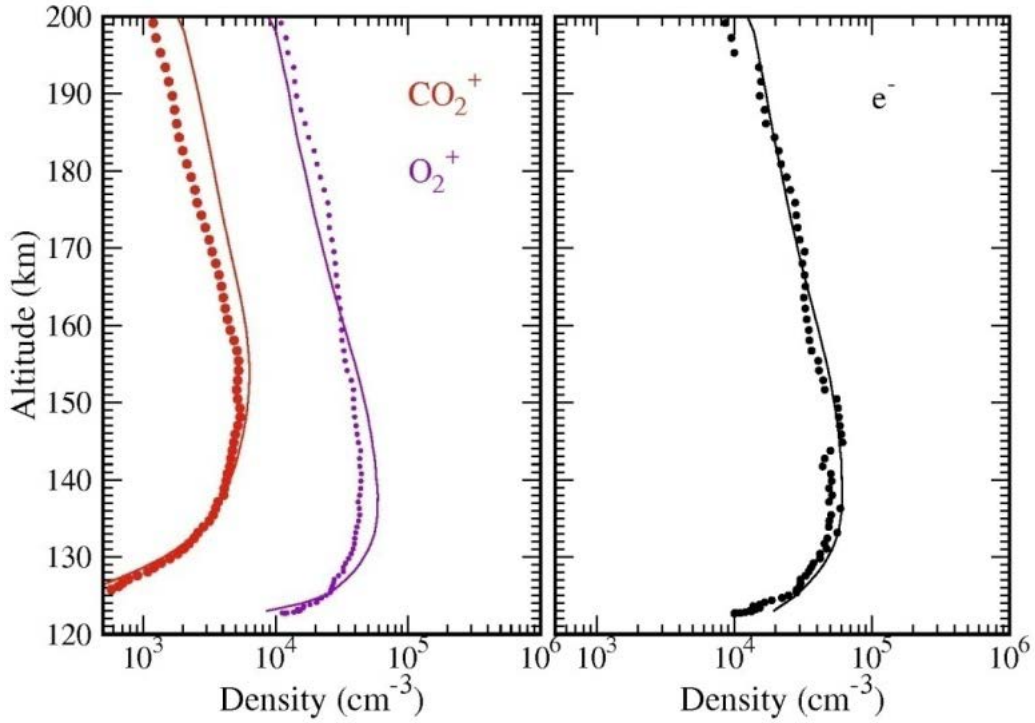


Fig 14: *The left panel shows the modelled profiles of CO_2^+ (red lines) and O_2^+ (blue lines) compared with the NGIMS observations (solid symbols) for the deep dip campaign 4 (DD4) orbit 1824. The modelled CO_2^+ (O_2^+) profiles are scaled by a factor of 2.5 (1.5) to make them in agreement with the observations. The right panel shows the modelled electron density profiles (lines) compared with the LPW observations (solid symbols) for the same orbit. The modelled profiles are scaled by a factor of 1.5 to make them in agreement with the observations.*

- **First Observation of Transport of Solar Wind Protons Scattered from Magnetic Anomalies into the Near Lunar Wake**

The first observational evidence for the transport of the solar wind protons scattered from the Lunar Magnetic Anomaly (LMA) on the dayside into the near wake region is obtained from analysis of SWIM data, when the Moon was located outside Earth's bowshock. The energy of such protons are either smaller or comparable to that of solar wind and have a wide angular distribution as observed by SWIM. The energy-time and direction-time spectrogram for such an event observed in orbit 1977 of Chandrayaan-1 during 09:30 UT to 11:28 UT on 20 April 2009 is shown in Fig.14.

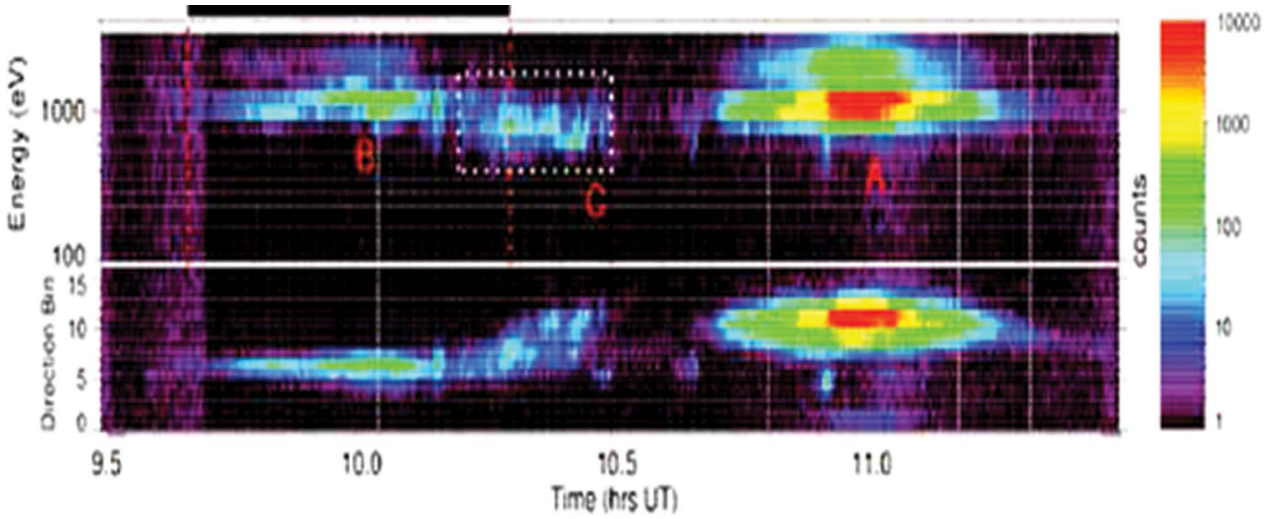


Fig 15: *Top panel Energy-time spectrogram from SWIM observations for the orbit 1977 of Chandrayaan-1. The horizontal axis shows time in hours' universal time. The black-filled box on the top indicates the time interval of SWIM observations in lunar wake (~09:42 to ~10:18 UT). A pair of dotted vertical lines in red color mark the wake entry and exit timings for Chandrayaan-1. Different population of ions observed by SWIM in this orbit are indicated as A, B, and C. The white coloured rectangle is used to highlight the population C observed during the day-night terminator crossing and extending into the wake. Bottom panel: Direction-time spectrogram. The vertical axis shows the 16 direction bins in which ions are observed by SWIM. Direction bin 0 refers to close to nadir, and direction bin 15 refers to close to zenith*

- **Acceleration of Solar Energetic Particles near 1.5 AU during Corotating Interaction Region (CIR) event: Evidence from MAVEN**

The dearth of observations between 1 AU and 3 AU limits our understanding of energetic particle acceleration processes in interplanetary space. In the present study, the energetic particle acceleration in a Corotating Interaction Region (CIR) using data from two vantage points, 1 AU (near Earth) and 1.5 AU (near Mars) has been studied. The CIR event of June 2015 was observed by the particle detectors aboard the Advanced Composition Explorer (ACE) satellite as well as the SEP (Solar Energetic Particle) instrument aboard the Mars Atmosphere and Volatile EvolutioN (MAVEN) spacecraft situated near 1.5 AU. The shocks associated with CIRs can accelerate energetic ions far beyond 1 AU, and these particles stream into the inner heliosphere, and most of

the previous observations are from regions beyond 3 AU. Using ACE and MAVEN observations, it has been shown, for the first time, that CIR shock can accelerate a significant number of particles even at 1.5 AU (Fig. 16).

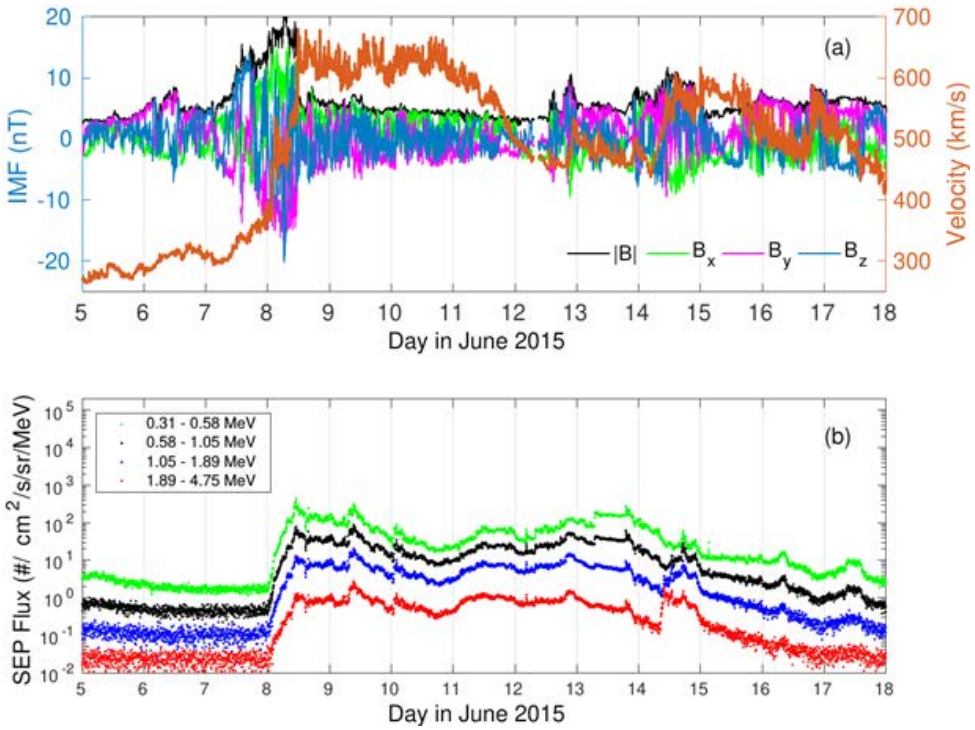


Fig 16:- *(a) The variation of IMF (left Y-axis) and solar wind velocity (right Y-axis) for the period 5-17 June 2015 observed by ACE at 1 AU. (b) The SEP fluxes at different energy ranges as observed by the EPAM sensor onboard ACE satellite for the period 5-17 June 2015. It is clear that the CIR reached the vicinity of Earth on 8 June 2015. The signature of the CIR arrival is seen as almost 2 orders of magnitude increase in the SEP*

- **Venus surface dielectric constant estimation using GMRT Observation**

The Venus surface thermal emission shows monotonous decrease of radiometric brightness temperature (Tb) with wavelength at microwave radio wave spectral regime. This issue has been addressed at SPL by conducting dedicated observations of Venus at decimetre wavelength using Giant Meterwave Radio Telescope (GMRT) at multi-frequency and dual polarization when Venus was at its closest position to Earth (July- September period of 2015). At decimetre (dcm) wavelengths, thermal radiation from the Venus has contributions from the atmosphere and the surface beneath it owing to the expected deep penetration depth of radiation to the low dielectric dry Venus surface. The polarimetric observations by GMRT provide all the four strokes parameters (I, Q, U, V) for studying the surface dielectric permittivity. The larger difference between the two orthogonal components towards the limb is manifested as an enhancement in the degree of polarization (DOP) which represents the fraction of the linearly polarized component to the total intensity of radiation as: DOP = (Q2 + U2)/I×100. The Stokes parameters measured at 607.67 MHz and 1297.67 MHz are used to derive the DOP of Venus. The concentric annular sections,

each of width of 1 arcsec for 1297.67 MHz and 2 arcsec for 607.67 MHz observations, starting from the centre all the way to the limb of Venus has been formed and then mean and the standard deviations of the DOP for each of the annular sections were determined. In Fig. 17, the DOP estimated from observations (filled circles) for each annular rings and theoretically calculated (continuous lines) for different dielectric values are shown as a function of the radial distance from the centre for at 607.67 MHz and at 1297.67 MHz, respectively. Radar observations of Venus by several workers including the Magellan observations determined the value of dielectric constant lies between 4 and 4.5. At these wavelengths, the surface could be relatively smooth and the effect of surface roughness is least expected and hence the estimated value of dielectric could be close to the real value. As the dielectric constant plays a major role in the observed Tb at microwave frequencies, the current results are essential for the theoretical calculations explaining the role of subsurface properties on decrease of Tb with wavelength.

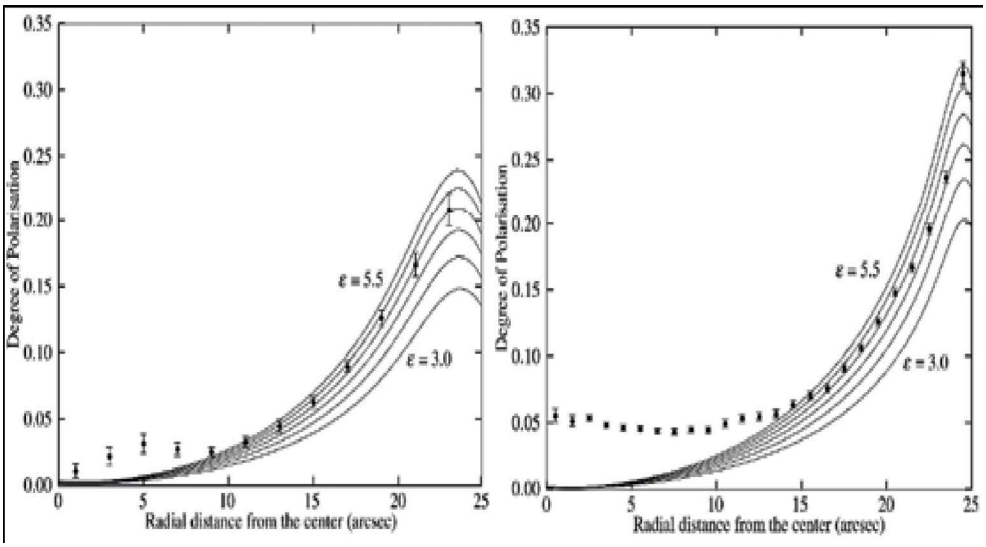


Fig 17: *Variation of the DOP at 607.67 MHz (left panel) and at 1297.67 MHz (right panel) with respect to the radial distance from the centre (solid dots). Vertical lines represent the standard errors in the measurements. Solid lines show the theoretical curves convolved with Gaussian corresponding to the GMRT synthesised beam plotted for dielectric constant = 3.0, 3.5, 4.0, 4.5, 5.0 and 5.5. There is a discrepant 3-5 % of polarization close to the centre of the disk which is attributed to the polarization intensity is dominated by the background noise which is ~0.1mJy for 607.67 MHz and ~0.15 mJy for 1297.67 MHz. The theoretical DOP begins to match with the observed DOP beyond ~10 arcsec at 607.67 MHz and about 15 arcsec at 1297.67 MHz which are when the signal begins to dominate the noise. The DOP near to the centre of the map is expected to be zero due to the rotational symmetry of the polarized radiation. Since the intensity of polarized emission is given by p = (Q2 + U2) , it can never be negative. Hence there is a non-zero mean positive bias to the noise. But the noise on the Venus polarization intensity near to the centre is of the order of the background noise which is prevalent throughout.*

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U R RAO SATELLITE CENTRE (URSC)
BANGALORE

UR Rao Satellite Centre (URSC) previously known as ISRO Satellite Centre (ISAC) is the lead center for satellite design, development and operations in the country. It is also involved in the realization of science missions and scientific payloads. During the year, 2018-2019 URSC had realised and launched 16 Satellites including one nanosatellite. URSC is actively involved in successfully operating the multi-wavelength astronomy satellite AstroSat launched in 2015 and also Chandrayaan-2, India second mission to the Moon launched during July 2019. It plays a major role in planning and operating the AstroSat satellite and Chandrayaan-2 orbiter for the required scientific observations.

A. BRIEF NOTE ON THE HIGHLIGHTS OF INSTITUTIONAL ACTIVITIES:

The centre is focussing on the realisation of various satellite missions for national requirements and is also in the process of readiness of the upcoming missions XPoSat, an X-ray polarimetry satellite and Aditya-L1, a dedicated solar mission at the first Lagrangian point L1 of Sun-Earth system.

The Space Astronomy Group (SAG) team at URSC is the nodal team which is involved in optical, X-ray and gamma-ray research with a strong emphasis on design and development of novel instrument concepts for space-based as well as ground payloads/facility. SAG is also involved in the analysis and interpretation of existing astronomical data from space- and ground-based facilities around the world. Extensive research is being carried out using observational data from ISRO's *AstroSat* observatory and recently launched Chandryaan-2 mission. Analysis of the data from the International Space Observatories is also pursued. In addition, Monte Carlo simulation tools are used for optimization of various system performance parameters such as detector sensitivity and response, estimation of expected background and complementing ground calibration activities.

SAG carries out strong science collaboration with National Institutes and Universities and had conducted a science meeting on "Transient Astronomy: Current Trends and Upcoming New Frontiers" during Nov 2019.

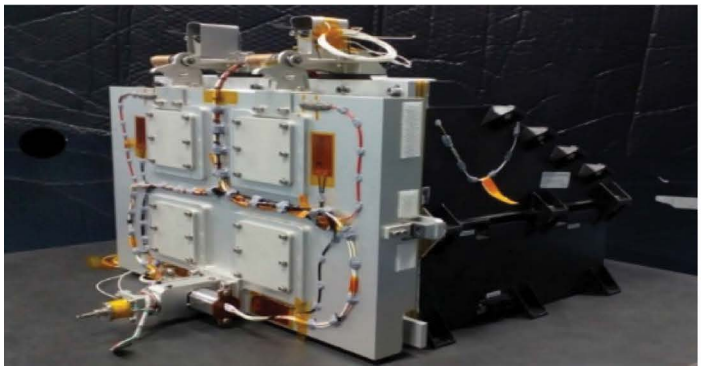
B. MAJOR FACILITIES/INSTRUMENTATION DEVELOPMENTAL ACTIVITIES

I. PAYLOAD DEVELOPMENT

- **CLASS on-board Chandrayaan-2**

Chandrayaan-2 Large Area Soft X-ray Spectrometer (CLASS) is an X-ray fluorescence

spectrometer on Chandrayaan-2 orbiter aimed at mapping the abundances of major rock-forming elements on the lunar surface. The instrument consists of swept charge devices (SCD) with a collimator, visible light blocking filters and signal processing electronics designed and built at URSC. The instrument is presently operational in the 100km lunar orbit on board Chandryaan-2.



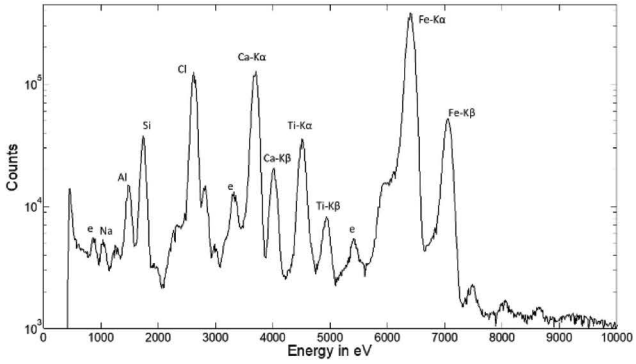


Fig 1: Left - *CLASS Flight instrument.* Right - *Spectrum of JSC-1A with Na line demonstrating the low energy capability of CLASS. 'e' in figure means escape peak*

- **SoLEXS and HEL1OS payload on-board Aditya-L1:**

Solar Low Energy X-ray Spectrometer (SoLEXS) on Aditya-L1 is a soft X-ray spectrometer (1 to 30keV) for studying solar flares. The main science goals of SoLEXS are: (i) Flare and coronal abundance studies as a standalone spectrometer and (ii) Dynamical events studies along with other payloads. Key instrument specifications are; energy range: 1-30 keV, Spectral resolution: < 250 eV @ 5.9 keV keV; Flare coverage: A to X-class.

High Energy L1 Orbiting X-ray Spectrometer (HEL1OS) on Aditya-L1 is a hard X-ray spectrometer (10 keV to 150 keV) to observe Sun as a star continuously from L1 point. The main science goal of HEL1OS is to study particle acceleration processes during flares, via emission of hard *X*-rays (HXR) and by studying its hard X-ray spectra.

Both these payloads are at various stages of development. The development is expected to be completed in 2021.

- **XSPECT payload for XPoSat**

X-ray Polarimeter Satellite *(XPoSat)* is India's X-ray polarimeter mission carrying Polarimetry in X-rays (POLIX) and X-ray Spectroscopy and Timing (XSPECT) experiments with their viewing angles aligned with each other. XSPECT provide unique opportunity to observe astrophysical sources for long durations to study their spectral and temporal variability in 0.8 to 15 keV X-ray band. The energy resolution of <200 eV @ 5.9keV and at -20°C and timing resolution of ~ 2 msec is planned. The instrument is under development and expected to be delivered in 2021.

- **VASP**

Venus Atmospheric Spectro-polarimeter (VASP) is a near-Infrared spectro-polarimeter (NIR-SP). NIR-SP provides a unique opportunity to study planetary atmospheres, which are composed primarily of molecules and aerosols.

- **AXIS**

Auroral X-ray Imaging Spectrometer (AXIS) is an imaging X-ray spectrometer. The broad scientific objective of AXIS is the spectroscopic observations of X-ray emission from Earth's atmosphere occurring due to electron bremsstrahlung causing aurora in polar regions, X-ray fluorescence emission triggered by solar X-rays, X-ray scattering by atmospheric atoms and solar wind charge exchange (SWCX) emission.The energy range of instrument is 0.3 - 2 keV.

II. Technology Development Activities

Technology development activities have been taken up keeping future science mission interests .A medium energy, large area X-ray spectrometer is being designed with Cadmium-Telluride (CdTe) based detector with spectral energy range of 10 – 100 keV. Development of Multi-slit spectro-polarimeter for solar atmosphere is in progress. Soft X-ray polarimeter based on GEM TPC configuration is being developed for future Astronomy mission. NIR spectro-polarimeter with Acousto-Optic Tunable Filter (AOTF) is being developed for planetary atmospheric study. Compact X-ray source development has been taken up for future in-situ X-ray experiments on moon and mars.

III. Major Facilities Established

New facilities have been established as a requirement for on-going payload development activities. Class 1000 and Class 100 clean rooms have been established to carryout assembly and testing of contamination sensitive instruments like SUIT (Solar Ultra violet Imaging Telescope – jointly with IUCAA) payload on-board Aditya-L1 mission. In addition, Class 100,000 and Dark Room facilities have been established for carrying out various payload assemblies and testing activities of Flight and Qualification Models.

Cleanliness levels are maintained through continuous monitoring of particle and molecular contamination levels. Instruments such as Laser Airborne Particle Counter, Surface Particle Counter, and Particle Fallout Photometer are available for the purpose. New instruments required for assembly and calibration of payloads such as Interferometer, High Resolution Spectrograph, Laser Sources, Baking Chamber, are made available.

IV. Major Instrument Development

- **Laboratory Model of Spectro-polarimeter Instrument:**

A near infrared spectro-polarimeter for planetary atmosphere exploration is being developed at

SAG, URSC. A spectro-polarimeter instrument is crucial for understanding the composition of planetary atmosphere as the spectroscopy gives signatures of gases whereas polarimetry gives signatures of dust and clouds. A dual AOTF based spectro-polarimeter is being calibrated for spectroscopic and polarimetric performance. Mueller matrix of AOTF is estimated using a NIR laser and a linear polarizer. Preliminary estimates of the Mueller Matrix suggest the polarimetric accuracy of the instrument to be better than 1%. This instrument is acceptedfor ISRO's future Mars and Venus mission.

- **Polarimeter for coronal magnetic field measurement – design aspects:**

A full Stokes-polarimeter for space-based solar coronal magnetic field measurements is designed with high efficiency for the weak Stokes-V (10^{-4} times Stokes I) signal while minimizing the cross-talk from Stokes-Q and -U. The polarimeter consists of a continuously rotating single crystal retarder as the modulator and a Wollaston prism as a dual beam analyzer at Fe XIII 1074.6-nm emission line. An optimum modulation matrix is derived taking into account the systematics and polarization cross talk due to satellite jitter. Jitter and drift from a low earth orbit satellite are considered in the simulation. The estimated cross-talk and the polarimetric efficiency are experimentally verified. A study on the polarized fringes produced by parallel-plate retarders is carried out for the placement of the retarder position inside the optical layout. The design of the Aditya-L1 polarimeter is based on this work.

C. CATEGORY WISE SPACE RESEARCH ACTIVITIES AND MAJOR RESULTS

- **Astronomy & Astrophysics**

Scientists from SAG are involved in research in the domain of high energy astrophysics, specifically on compact objects. SAG has strong collaboration with various Institutes and Universities on their research activities. The major results are briefed below.

- **Studies of Galactic Black Hole (GBH) Sources**

MAXI J1535-571: AstroSat Target of Opportunity (ToO) observation was triggered on the source in the second week after its detection on Sep 02, 2017 by MAXI onboard ISS. Prominent C-type Quasi-periodic Oscillations (QPOs) of frequencies varying from 1.85 to 2.88 Hz, along with distinct harmonics were detected. Two-component spectral fitting of the data provides an estimate of a black hole mass between 5.14 and 7.83 $M_{\odot}$.

IGR J17091-3624: Broadband spectral modelling of the transient source IGR J17091-3624 was carried out with Swift/XRT and NuSTAR data to understand the accretion flow dynamics based on two component flow model with a 'q' shape profile in Hardness-Intensity Diagram (HID) and the X-ray variability observed appears to be coupled with the intermediate state.

Studies of Neutron Star (NS) Sources : GX 17+2: The bright and persistent NS-LMXB, classified as Z-source traced out a complete Z-track in the hardness intensity diagram (HID). A normal branch oscillation (NBO) with a centroid frequency of 7.42 ± 0.23 Hz at the middle of the NB was also detected. There appears to be a possible trigger of an outflow of the disc material into the corona by radiation pressure.

Studies of X-ray Transient Sources: Scanning Sky Monitor onboard AstroSat observed number of X-ray sources. A new transient MAXI J1535-572 was observed by SSM during peak of the outburst. GRS 1915+105 was observed to be in 'λ' class. Crab flux variations are brought to less than about +/-15 %. SSM light curves are made available in the SSM website hosted at ISSDC.

- **Solar System Bodies including Planetary Science**

At URSC the research areas on this topic have been on lunar and planetary surface composition and atmospheres. Research on Solar & space weather is also carried out.

Surface composition of the Moon: CLASS on Chandrayaan-2, currently in orbit around the Moon has been measuring X-ray fluorescence lines from the lunar surface. CLASS is able to measure the lines of O, Mg, Al and Si even for very low activity levels of the Sun. CLASS is the first such instrument to measure the Oxygen X-ray fluorescent line.

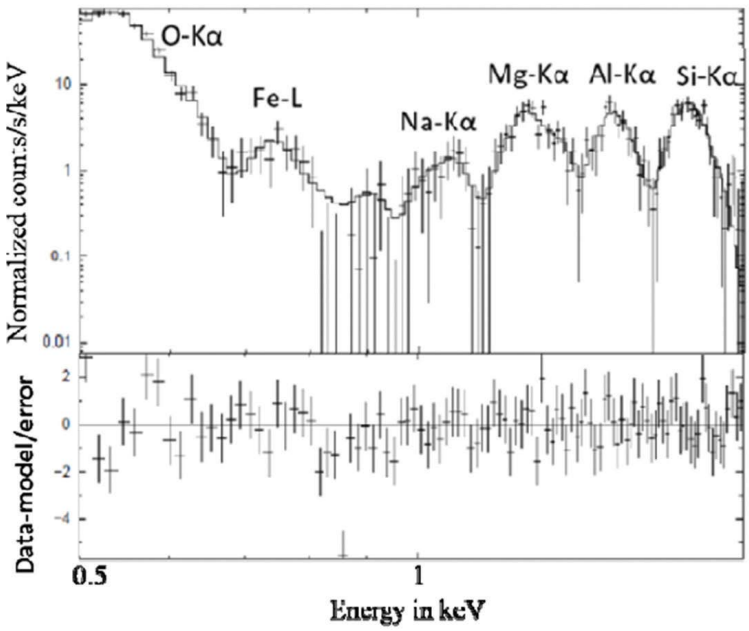


Fig 2: *Lunar X-ray spectra in the imbrium basin region fitted with a model with lines and scattered continuum.*

Laboratory measurements for integrated analysis: In collaboration with the Planetary Science Laboratory (PSL) at DLR, UV to mid-IR reflectance spectroscopy was done at very controlled geometric conditions for 12 geological samples from India

X-ray emission from Earth, Mars and Venus: X-ray emission from exospheres of Venus, Mars and upper atmosphere of Earth were simulated taking into account the different physical processes towards optimising design of X-ray spectrometer concepts for studying X ray emission from these planets.

Polarization Signature of Mars atmosphere: Study of polarisation of sunlight scattered from planetary atmospheres can help to understand the composition as well as size distribution of clouds and aerosols. A line-by-line, multiple scattering vector-radiative transfer forward model based on successive order of scattering was developed to analyse and understand the polarisation signatures of Mars atmosphere and results were compared with another well-known model based on Adding Doubling method.

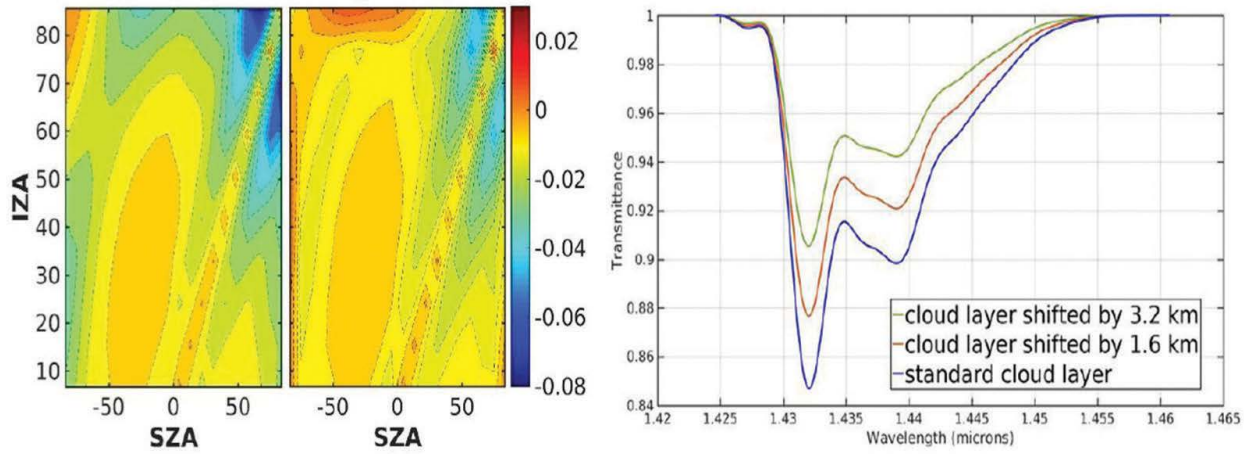


Fig 3: Left - *Scattered polarization in the Nadir direction at 1200 nm for the cases of only Dust and Dust+H2O ice (IZA - Instrument Zenith Angle; SZA - Solar Zenith Angle).*
Right - *CO2 absorption band in the Venus atmosphere and it's variation with changing cloud top altitude.*

- **Solar & Space Weather Research:**

At URSC the research areas on this topic have been on dynamics of solar magnetic field and space weather aspects.

Relation between Solar Flares and CMEs: Solar flares and coronal mass ejections (CMEs) are two very important active events and the relation between them and influence on Earth's atmosphere is so far not well established. For the first time, the Halo CMEs are categorized into four different groups and is shown that: (a) there is a good correlation between flare flux and peak intensity and CME parameters (b) correlation is poor with flare duration; and (c) For CMEs before or after the flare, the correlation is lesser than the CMEs occurring during the flare.

Data Reduction Technique for Lenslet Array Spectroscope: Snapshot spectroscopic imagers/ instruments (SSI) are a class of spectroscopic instruments that are capable of acquiring spectral information of a given field of view in a single frame. Snapshot capabilities of this instrument are

demonstrated by studying the dynamic activities of the Sun as inferred from two measurements: (i) Evershed flow in a sunspot in NOAA 12526 at Fe I 6301.5Å and (ii) oscillations in a quiescent prominence at Hα 6562.8Å. This instrument can be used for large or small scale structures, making it efficient for studying a wide range of dynamic activities like Moreton waves, prominence oscillation etc.

Connection between Active region complexity and Solar Flare strength: Sunspots are classified as α, β, γ, and δ with the complexity of the magnetic topology increasing from α to δ. An existing automated algorithm (SMART-DF) is modified and used to identify δ-spots for the existing full disk SOHO/MDI data and compared with the NOAA-SRS database. The connection between formation of δ-spot and flares is carried out using GOES flare flux and NOAA-SRS sunspot classification.

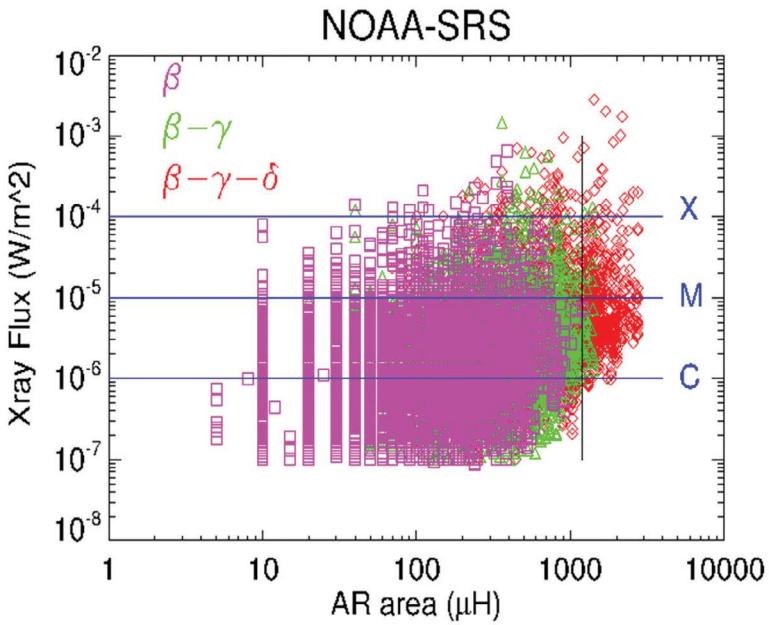


Fig 4: *Correlation of Active Region Area with Flare Flux for all complex activities.*

C. **Onboard Automated CME Detection Algorithm for the Visible Emission Line Coronagraph (VELC) on Aditya-L1:** One of the primary objectives of VELC is to study the dynamics of coronal mass ejections (CMEs) in the inner corona. An onboard automated CME detection algorithm to optimize observation and storage based on intensity and area thresholding in successive difference images that are spatially rebinned is applied on the data from space-based coronagraphs such as STEREO/SECCHI COR-1 and K-Cor, a ground-based coronagraph. The algorithm is also tested on synthetic CMEs of different types after including the expected photon noise for VELC.

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SPACE APPLICATIONS CENTRE (SAC)

Ahmedabad

Space Applications Centre (SAC) is one of the major research & development Centres of Indian Space Research Organization (ISRO). SAC leads the development of advanced remote sensing payload systems, image processing softwares and applications for Earth Observation, Space Science & Interplanetary missions.

During the reporting period, SAC delivered more than 15 payloads for Earth Observation and Interplanetary missions. It includes payloads for India's first Hyper Spectral Imaging Satellite (HySIS), CARTOSAT-3 series with very high resolution capabilities in PAN and MX bands, GISAT-1 satellite with high resolution capabilities from Geostationary orbit, INS-1C Nano satellite, RISAT-2B series satellites with multi-mode X-band SAR payload capable of day and night all weather imaging with fine resolution of up to 0.5m. It also includes payloads/payloads sub-systems for interplanetary missions including Chandrayaan-2 and Aditya-L1. SAC also developed the algorithms, the software required for processing, and product generation of data acquired from the above Remote Sensing satellites as highlighted in the report. Payloads for Chandrayaan-3, RISAT-1/-2 series, Scatterometer, CARTOSAT-3 series, GISAT series, Resourcesat-3 series, Oceansat-3 series, NASA-ISRO SAR (NISAR) and HRSAT constellation are under development.

SAC conceptualizes and develops Remote Sensing and Geo-spatial applications covering projects/ activities related to understanding Earth system, its components, processes and interactions using earth observation data and applications towards societal benefits. In addition, space data analysis for planetary sciences is carried out.

During the reporting period Earth Observation (EO) Applications related to marine biological system, ocean color, ocean bio-geo-chemistry, marine lithosphere, coastal processes, geo hazards, mineral exploration, geo-archaeology, desertification and land degradation, Himalayan and Polar cryosphere, improved techniques for crop assessment and forecasting, assessment and modeling terrestrial biosphere, impact study of climate change and hydrological modeling are carried out. SAC Web Portals VEDAS and MOSDAC are providing near real time data dissemination involving organizing and maintaining various data bases, thematic map library, satellite data product repository, development of database applications, web-based software, tools and data utilization services.

A. MAJOR FACILITIES/PAYLOADS DEVELOPED

- **REMOTE SENSING PAYLOAD SYSTEMS**

Following major payloads were realized during the reporting period.

➢ Hyperspectral Imaging

Hyper Spectral Imaging Satellite (HySIS): HySIS comprising two spectrometers, one each in VNIR and SWIR range were realized. The major highlight has been the realization of a completely indigenous spectrometer with indigenous gratings (Fig.2), VNIR detector, cooler electronics and CAN like interfaces. Payload was launched on November 29, 2018. Excellent quality images have been obtained. Presently this is the only Hyper Spectral Imaging Satellite (VNIR +SWIR) in orbit.

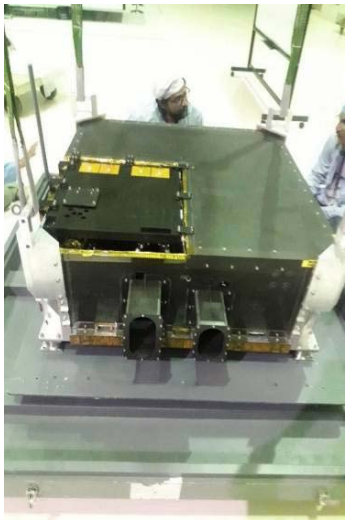


Fig.1: *VNIR & SWIR payloads*

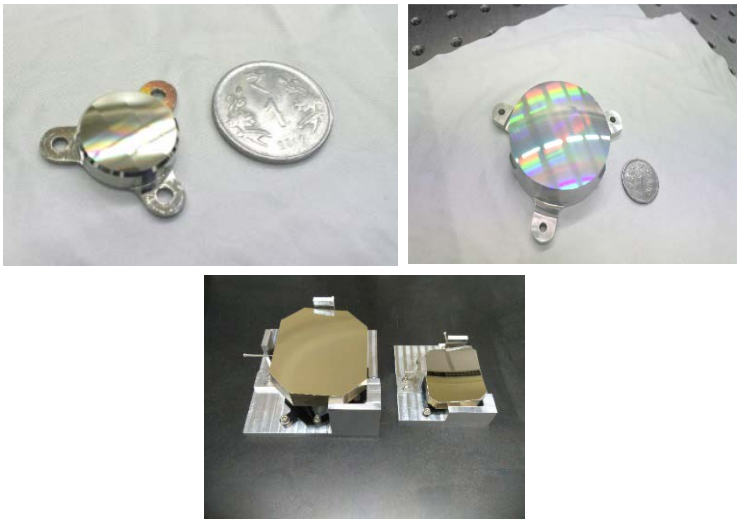


Fig.2: *SWIR & VNIR Gratings & Metal Mirror*

➢ High Resolution Cartography

CARTOSAT-3 Series: These are the next generation of cartographic application satellites envisaged to meet the increasing user demands for very high-resolution Panchromatic and Multispectral imagery for cartographic applications. Payload for Cartosat-3 was successfully delivered. Development of Cartosat-3A is in progress.

Fig.3: *Carto-3 EOM integrated with Payload Electronics & FPA*

Fig.4: *GISAT Payload*

➢ **High Resolution Geo-Imaging**

GISAT Series: Geo Imaging Satellite is envisaged to provide high resolution imaging capability from geostationary orbit. It will comprise of high-resolution imaging in VNIR (GISAT-1/-2) and LWIR (GISAT-2). There will be two hyperspectral imagers covering VNIR and SWIR regions. GISAT-1 payload was successfully delivered to the project.

➢ **Micro and Nano Satellites** Microsat satellite carries first electro-optical night imaging payload from LEO orbit in MWIR & LWIR bands. Nano satellite (INS series) carries payload with first reflective based origami optics and Aluminium based Mirrors.

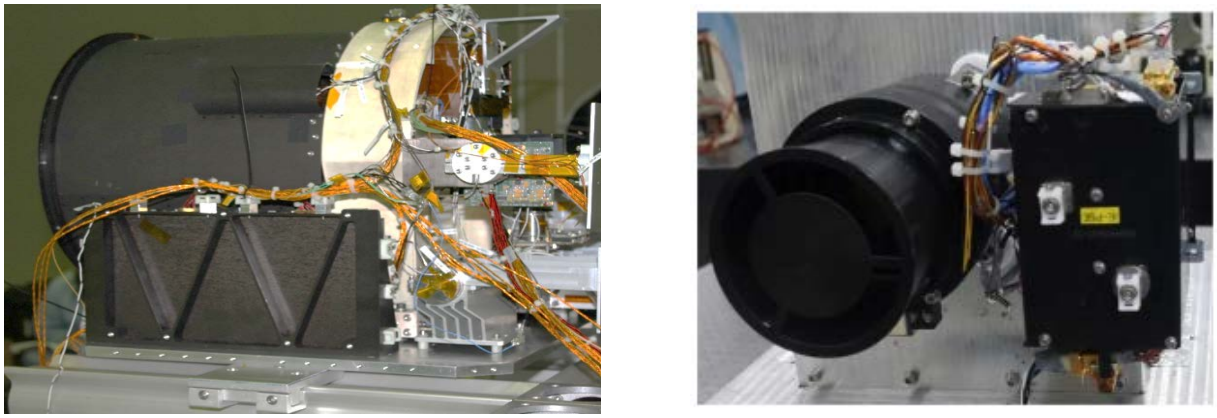
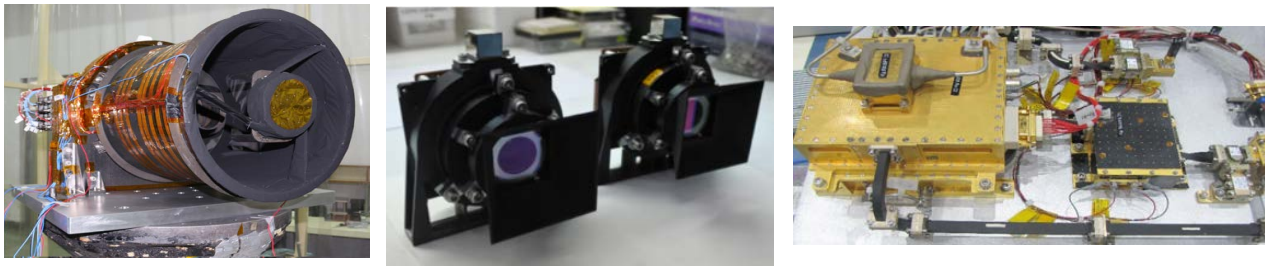


Fig.5: *Microsat payload (left) and INS payload (right)*

- **INSTRUMENTATION/PAYLOAD FOR SOLAR SYSTEM BODIES**

➢ **Chandrayaan-2** is a follow on mission of Chandrayaan-1. SAC delivered payloads including Terrain Mapping Camera (TMC-2), Imaging Infrared Spectrometer, Orbiter High Resolution Camera, Synthetic Aperture Radar, Lander Position Detection Camera (LPDC), Lander Hazard Detection Avoidance Camera (LHDAC), and Lander & Rover Imagers & Ka-Radar Altimeter with Hazard Detection & Avoidance Processor. New technologies like metal mirrors, ASIC based Miniaturized Camera, Cooler Drive Electronics, and Payload Temperature Management.



Orbiter High Resolution Camera (PAN: 0.25m)

LPDC & LHDAC

Ka- Radar Altimeter

Fig 6: *Chandrayaan-2 payload*

- **ADITYA-L1** Visible Emission Line Coronagraph (VELC), on-board Aditya-L1 space mission, is an internally occulted solar coronagraph capable of simultaneous imaging, spectroscopy and spectro-polarimetry close to the solar limb. This activity is a joint activity between SAC and Indian Institute of Astrophysics (IIA). SAC is developing Detector and Camera Electronics systems for VELC payload. VELC will consist of four Detector Head Assemblies (DHAs) catering to three visible and one near Infrared channels. 11 packages along with Checkout Hardware and Software were delivered to IIA for payload level integration and testing at IIA.

B. SATELLITE DATA PROCESSING ACTIVITIES

- **Cartosat-3** Data Products Generation System (DPGS) was realized for processing data from high-resolution camera viz., PAN (0.28m) and MX (1.1m) after Cartosat-3 launch.

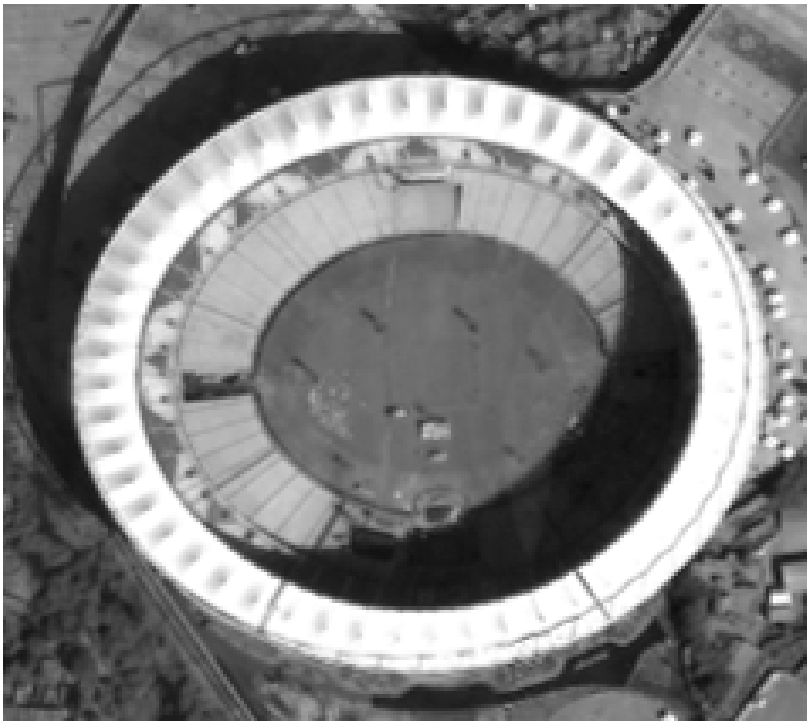


Fig.7: *Images from Cartosat-3*

- **CHANDRAYAAN-2** Data Products Generation Software (DPGS) was operationalized for Terrain Mapping Camera-2 (TMC-2), Imaging IR Spectrometer (IIRS) and Orbiter High Resolution Camera at Indian Space Science Data Centre (ISSDC), Bangalore. Using reference image, location accuracy better than 100m and vertical accuracy better than 50m was achieved.

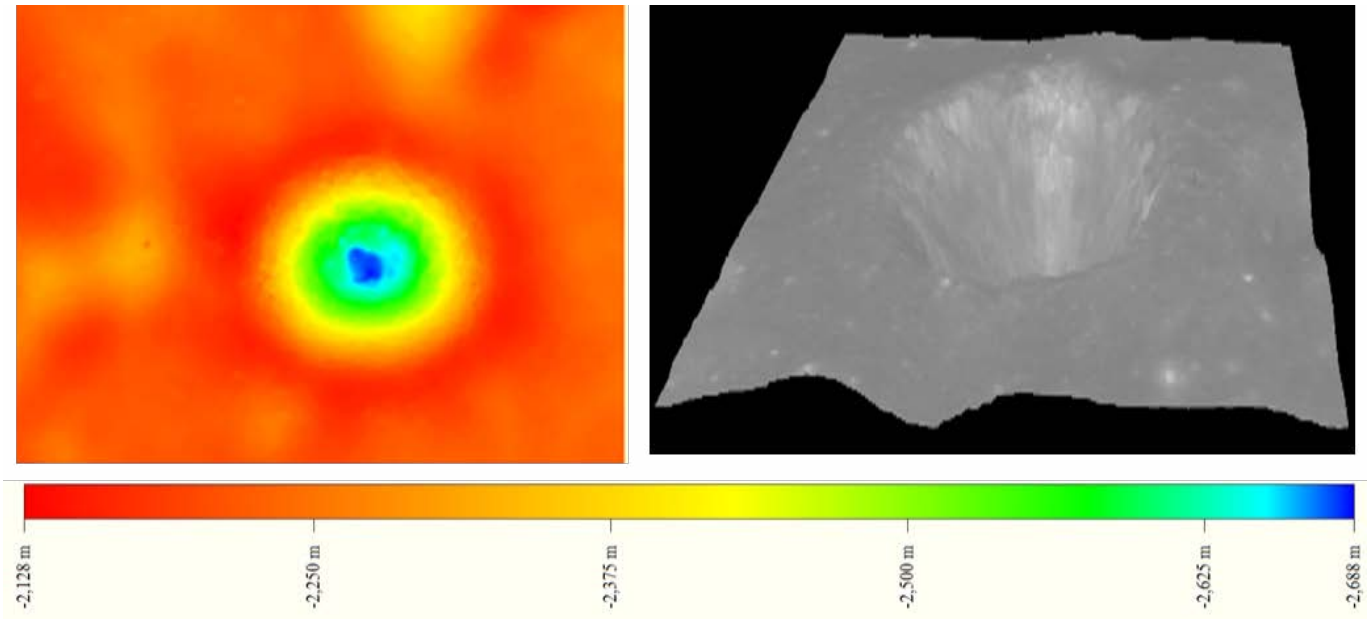


Fig.8: *TMC-2 DEM generated @ 10m and 3D draped View*

- **Chandrayaan-2 Dual Frequency SAR** Calibrated data products were generated for Lunar Polar regions in L-Band Full Polarization (FP) and Circular Polarization (CP).

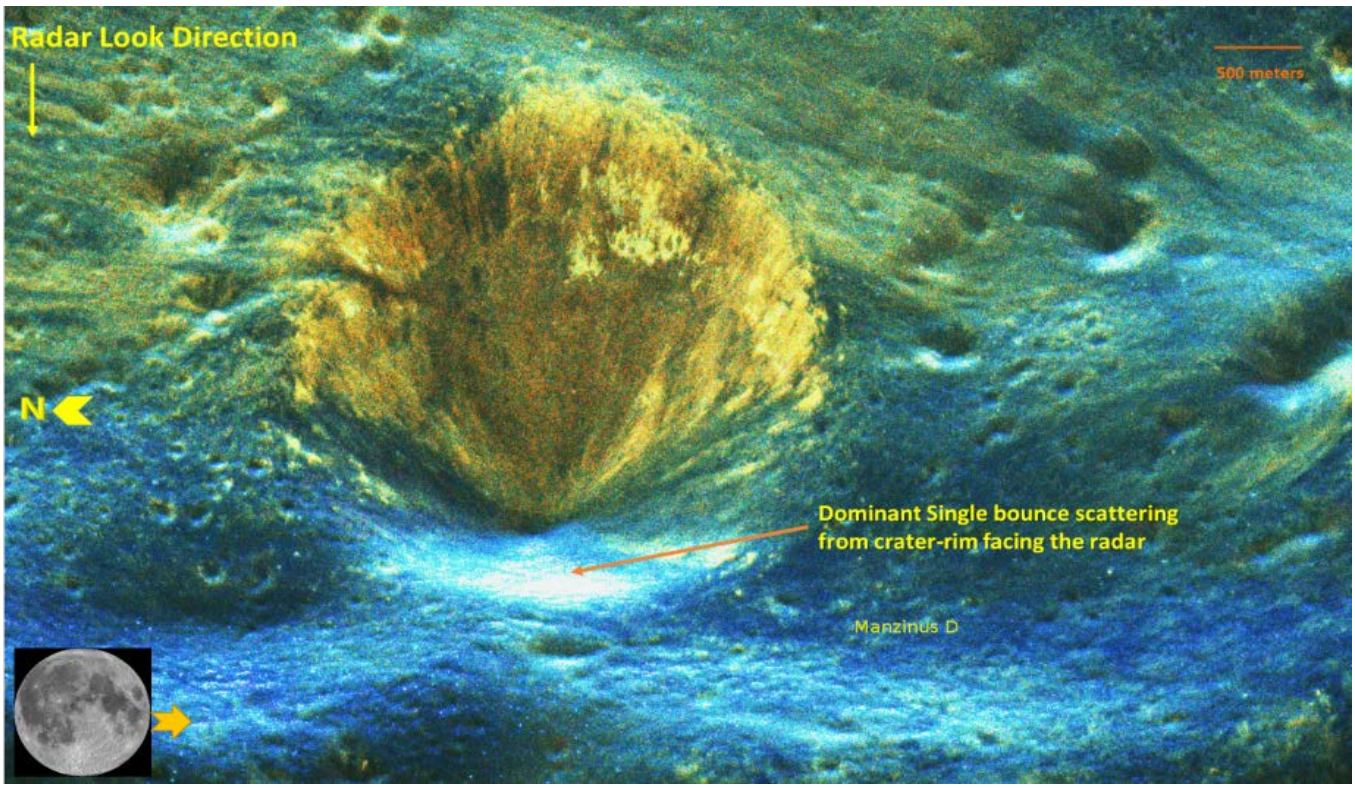


Fig.9: *High resolution (4m) L-Band SAR image of an unnamed crater inside Manzinus D Crater in CP*

C. MAJOR APPLICATION ACTIVITIES / PRODUCT GENERATION:

- **OCEANIC AND ATMOSPHERIC SCIENCES AND APPLICATIONS:** Ocean forecasts are being provided to different stakeholders (Shipping Corporation of India, Indian Navy, ISRO missions like RLV-TD, etc.) using satellite data assimilative wave and circulation forecasting models. Significant Wave Height from AltiKa, Jason2 and Jason3 are assimilated into very high resolution (2.5x2.5 km) wave model. Data assimilative ocean wave forecast model has also been installed at INCOIS in their configuration. Prediction of El-Nino with sufficient lead time is important to plan and establish many marine activities. Regarding this El-Nino forecasts were made using coupled ocean-atmosphere models. Oil Spill model and Langrangia Coherent Structure core analysis has been demonstrated for the Chennai oil spill 2017.Coastal inundation forecast model is made operational. A new approach, using satellite derived sea surface temperature, sea surface chlorophyll concentration, sea surface height anomalies (providing eddies), sea surface currents and sea surface winds, for Potential Fishing Zone PFZ has been developed, which is useful for giving probabilistic PFZ outlook even under cloudy conditions. The cyclogenesis, track, and intensity predictions using Indian satellites, experimental high resolution short-range weather forecasts are provided operationally through Meteorological and Oceanographic Satellite Data Archival Centre (MOSDAC). MOSDAC. It is also being provided to several agencies as per their requirements.

- **INSAT 3D/3DR AND SCATSAT-1 OPERATIONAL PRODUCTS:** Various new retrieval algorithms were developed for INSAT-3D/3DR Imager and Sounder instruments under an MoU between Antrix Corporation Limited and India Meteorological Department (IMD) for the establishment of Multi Mission Meteorological Data Receiving and Processing System (MMDRPS) facility at IMD, New Delhi. Significant improvement towards retrieval of ocean surface vector winds from Scatsat-1 has been achieved in the latest operational version (v1.1.3) of data products. High resolution analysed winds from Scatsat-1 has been operationalized at MOSDAC.

- **ADVANCED HYPERSPECTRAL DATA ANALYSIS SOFTWARE (AVHYAS-VER.1)** is an in-house developed tool for the processing and analysis and visualization of multi-/hyperspectral data. AVHYAS toolbox is plugged in with QGIS platform (an open source GIS environment) to have the GIS capabilities. Presently, AVHYAS-ver.1 tool is under rigorous testing by technical evaluation committee and subsequently will be released for all users.

- **MICROWAVE DATA ANALYSIS SOFTWARE (MIDAS)** designed and developed in-house with a focus on SAR polarimetry and other SAR applications has received a copyright.

- **FOREST ABOVE GROUND BIOMASS (AGB)** estimation using SAR data in Assam, Meghalaya and Madhya Pradesh; Assam results reported in ISFR-2019. Impact of vegetation density changes on Asiatic lion habitat at Gir National Park was studied over a five-decade period, using remote sensing in a joint study with Gujarat Forest Department.

- **SHOOL**, a low-cost soil-moisture sensor was developed in-house and qualified for performance at par with commercial sensors. This is being taken up for commercial production by a Startup venture. SM estimation (10km resolution) using SMAP radiometer data; products are operationally available on VEDAS and MOSDAC; further work on high resolution, high accuracy SM is in progress

- **AGRICULTURAL SCIENCES AND APPLICATIONS:** A new set of Rabi as well as short & long duration Kharif crops were discriminated using time series multispectral data and C-band SAR cross-pol data through conventional as well as machine learning (ML) approaches. ML approach showed substantial improvement in the discriminability as well as estimated crop acreages than the conventional approach. Use of satellite-derived yield proxy in the smart sampling technique for demarcating locations of Crop Cutting Experiments (CCEs) and their optimization lead to a reduction in the order of 50% for a crop insurance unit in CCEs. The operational application has been carried out for rice, mustard and wheat crop CCEs along with MNCFC, New Delhi.

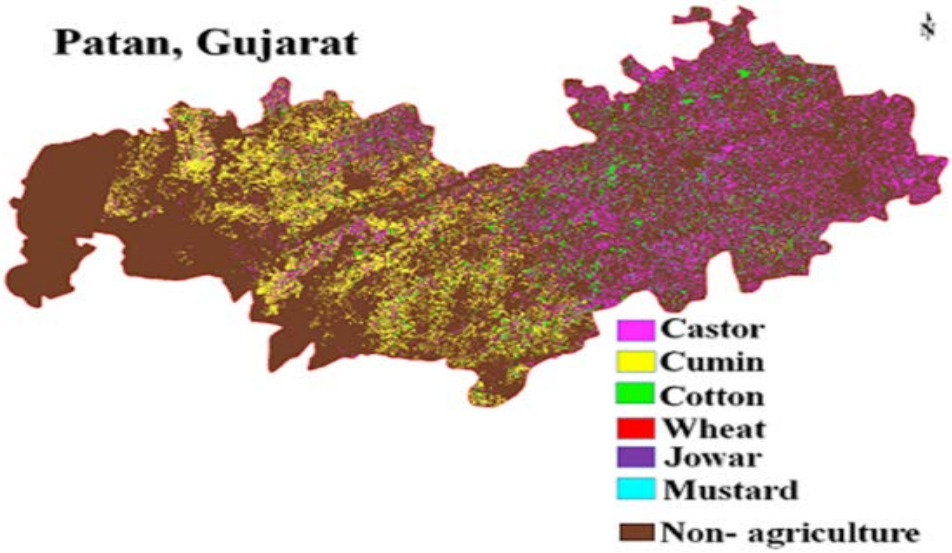


Fig 10: *Crop map prepared using time series multispectral data and C-band SAR cross-pol data through conventional as well as machine learning (ML) approaches*

- **ENVIRONMENTAL SCIENCES AND APPLICATIONS:** Scientific studies to understand the effect of lockdown on environmental parameters over India using spaceborne and ground based data have been carried out involving atmospheric gases, aerosols, surface temperature and water quality. A significant reduction of the order of 40-70% in the tropospheric NO_2 concentration has been observed over various cities of India, suggesting an effect of reduced anthropogenic activities in India. In addition, night-time surface cooling, decrease in forest fire count, crop water demand and increase in productivity (up to 30%) were observed for Rabi crops.

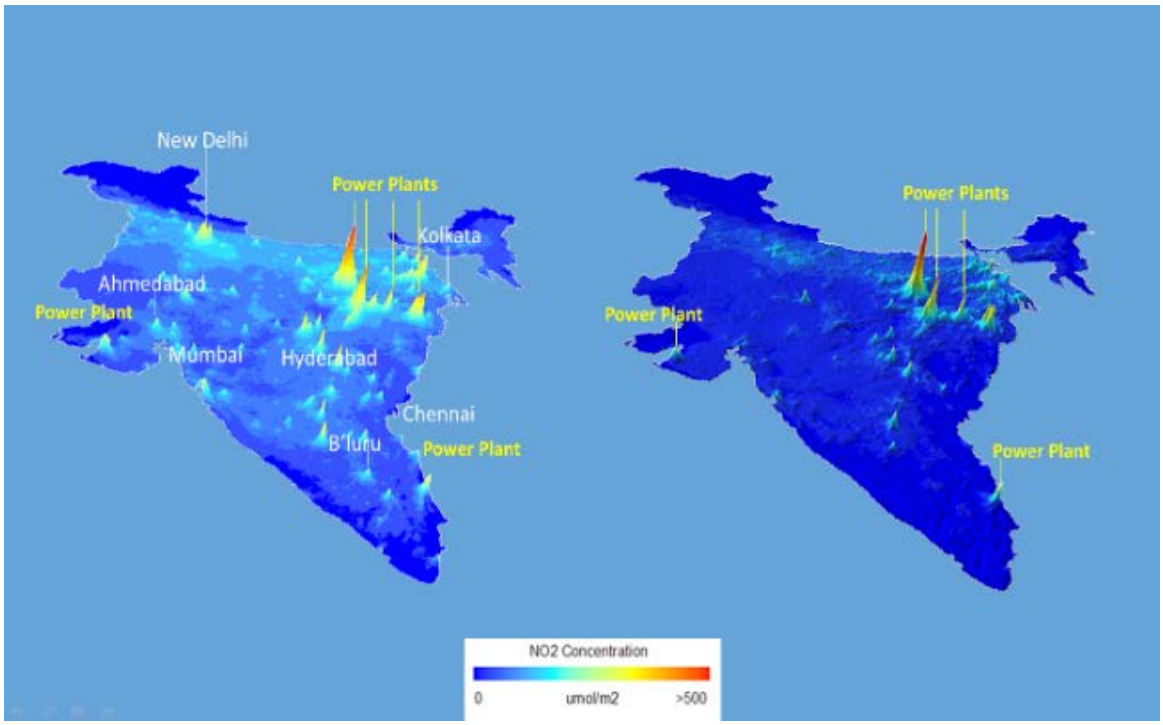


Fig 11: *Tropospheric NO2 concentration over India before lockdown and during lockdown period.*

- **GEOSCIENCE RESEARCH AND APPLICATIONS:** Desertification and Land Degradation Atlas for the selected districts of India at 1:50, 000 scale using IRS LISS-III data (2011-13 and 2003-05) was prepared and published. GIS based methods for Land Degradation Vulnerability Assessment (LDVA) using satellite derived data, socio-economic data, climate data and other ancillary data sets was developed and demonstrated for selected districts across India. Activities carried out on assessing the seismic hazard along the Himalayan region and Koyna-Warna reservoirs using in-situ and satellite observations. like from GPS, InSAR etc. have been carried out. Extensive deformation studies associated with the Barren Volcano and an Earthquake swarm at Palghar region (Maharashtra) have been completed. Regions affected due to land subsidence in the vicinity of Delhi NCR were identified using InSAR technique for 2014-19 time frame. Shoreline change Atlas of the entire country has been prepared at 1:25, 000 scale using LISS-4 data (for 2004-06 & 2014-16 time frame). Rip current forecasting system has been made operational on MOSDAC to issue alerts on rip current danger for nearly 175 Indian beaches. GNSS/NavIC drifters are designed and fabricated at SAC to measure rip currents and used for validation of rip current forecasts.
- **CRYOSPHERE SCIENCE AND APPLICATIONS:** Variability of snow facies over Himalayan-Karakoram regions for ~1300 glaciers were studied using information retrieved from ~1352 RISAT-1 MRS dual-pol. The study indicated no significant increase or decrease observed in snow cover from North-West to Eastern Himalayas but high variability of snow cover observed in parts of Indus, Chenab and Satluj sub-basins. Towards monitoring of glacier boundaries in H-K region, 5234 glaciers were mapped from two sets of data (2001-2003) and (2016-

2019). Surface ice velocity database was generated for ~1500 glaciers of Indus, Ganga and Brahmaputra basins. Generation and analysis of ice sheet and sea ice products was carried out. A book titled “Exploring the Antarctica” has been published containing the highlights of various scientific studies in the Antarctic region undertaken by Space Applications Centre.

- **PLANETARY SCIENCES:** Preliminary analysis of Chandrayaan-2 IIRS data suggests that it could successfully measure the variations in the reflected solar radiation that bounces off the lunar surface from different kinds of surface types. The variations in the spectral radiance are primarily due to the mineralogical/compositional variations that exist in the lunar surface and also due to the effect of space weathering. Chandrayaan-2 Dual-frequency Synthetic Aperture Radar (DFSAR) is imaging the lunar-poles to enable first-ever fully-polarimetric L-band observations. Data is being analysed to study scattering mechanisms and physical processes of the lunar surface (mainly, the Permanently Shadowed Regions) through various decompositions and estimation of parameters, amenable only using fully-polarimetric data.

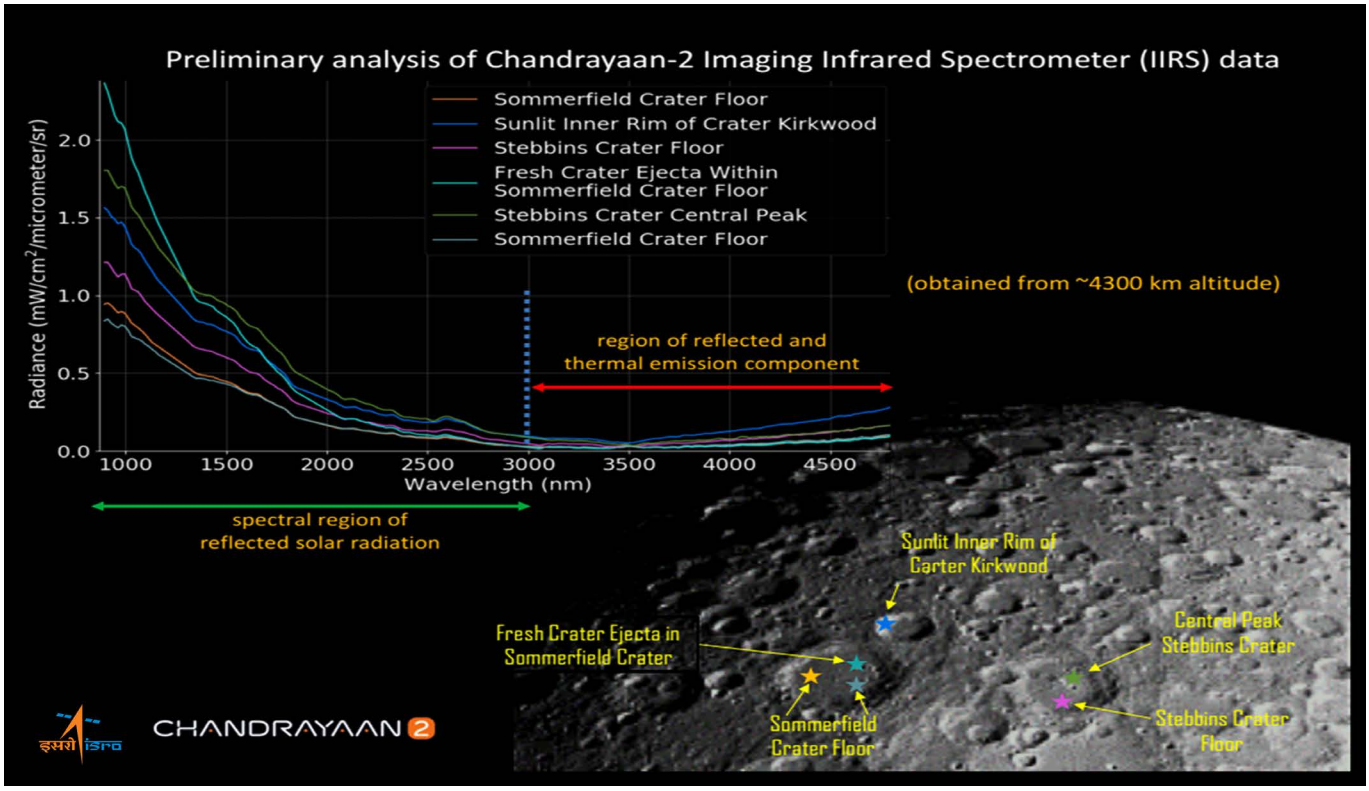


Fig 12: *Locations of the region of interests (ROIs) in the image (marked as colored stars) and corresponding spectral radiance profiles for different surface types such as crater central peak, crater floor, sun-lit inner crater rim.*

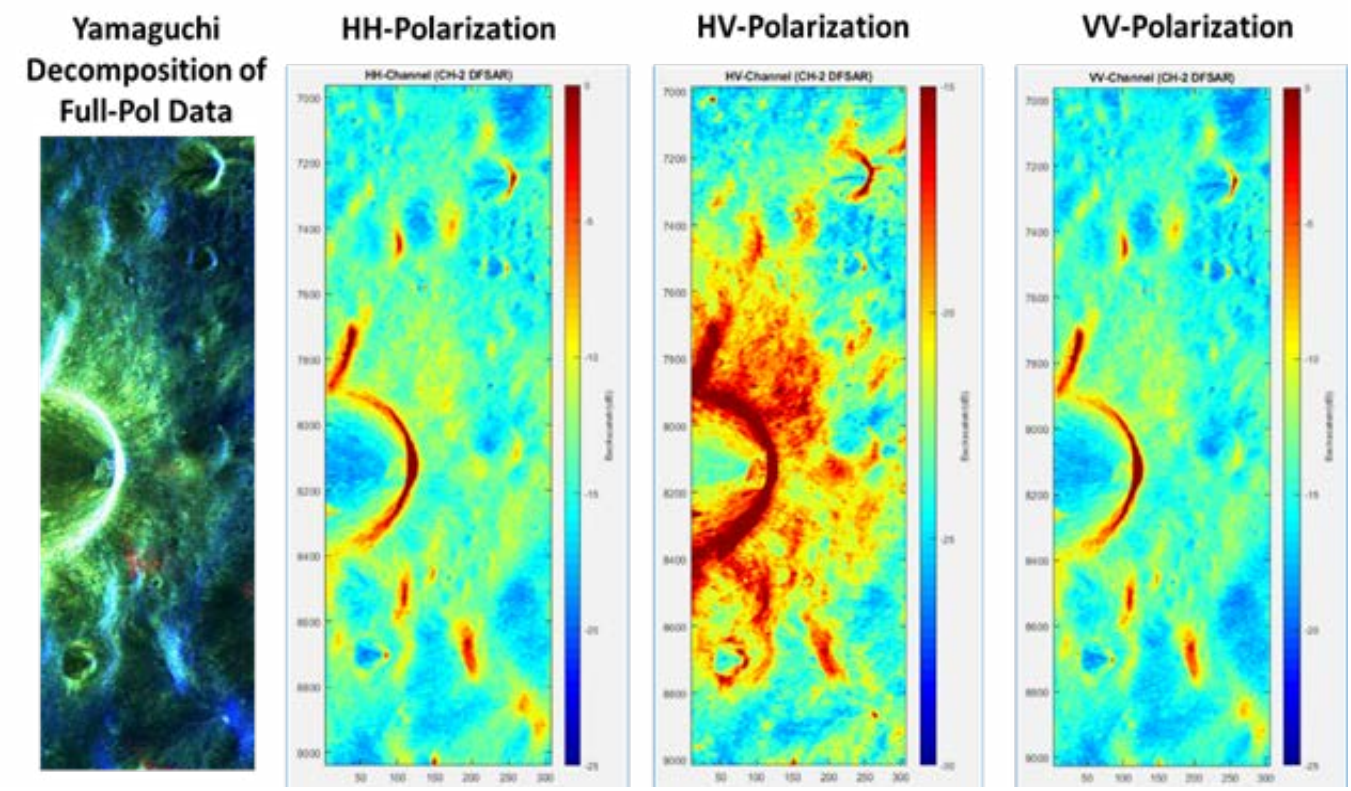


Fig 13: *A craterlet on the floor of Peary Crater near North Pole of the Moon. Number of polarimetric parameters like, circular polarization ratio, entropy, alpha angle, etc are being derived and studied for lunar characterization.*

- **CALIBRATION AND VALIDATION PROGRAMME**: A permanent Synthetic Aperture Radar (SAR) calibration site has been established at Antarctica by SAC-ISRO during 38th Indian Scientific Expedition to Antarctica (ISEA) (Dec 2018-May 2019). During 39th expedition, the CR network has been densified. The radiometric calibration of HySIS sensor has been fine-tuned vicariously using Little Rann of Kutchh (LRK) site campaign measurement. At operational data product generation these coefficients are implemented after validation and verification. Periodic radiometric performance of optical sensors (INSAT-3D, -3DR, and OCM2) are monitored using Deep Convective Cloud, Desert and Ocean targets. The techniques for non-linear trending algorithm for the radiometric stability is developed which shows predictive capability up to 3 months in advance for the optical channels.

Fig 14: *Corner reflectors installed at Antarctica during 39 ISEA*

- **VISUALIZATION OF EARTH OBSERVATION DATA AND ARCHIVAL SYSTEM(VEDAS)** website (https://vedas.sac.gov.in) contains vast and varied geospatial information available for visualization and analysis. Some of the important applications and web-analysis tool developed and serviced through VEDAS are (i) Vegetation Monitoring, (ii) New & Renewable Energy, (iii) Urban Sprawl Information System, (iv) Hydrological applications, (v) Cryosphere Applications and (vi) Air Quality Monitoring.In order to support data driven decision making for agriculture, VEDAS has designed and implemented visualization and analysis of AWiFS NDVI composite image over India. In addition to this, NDVI generated from other satellite data like MODIS and Sentinel2- NDVI are also available at country level for visualisation and analysis. VEDAS has developed 'Geospatial Calculator' as a web processing service that allows user defined single and multiband operations to be performed on a set of images. A fully automatic application on VEDAS for Flood monitoring (Assam & Gujarat state) using Sentinel-1 data. Developed deep learning based algorithm, calculated and published decadal urban sprawl of 100 smart cities of India using IRS LISS-4 data. VEDAS has developed Solar and Wind Calculators Android Apps for tapping potential of renewable energy. Under hydrological applications, Altimeter and Scatterometer derived water level at selected locations (~150) over rivers and reservoirs can be analysed.

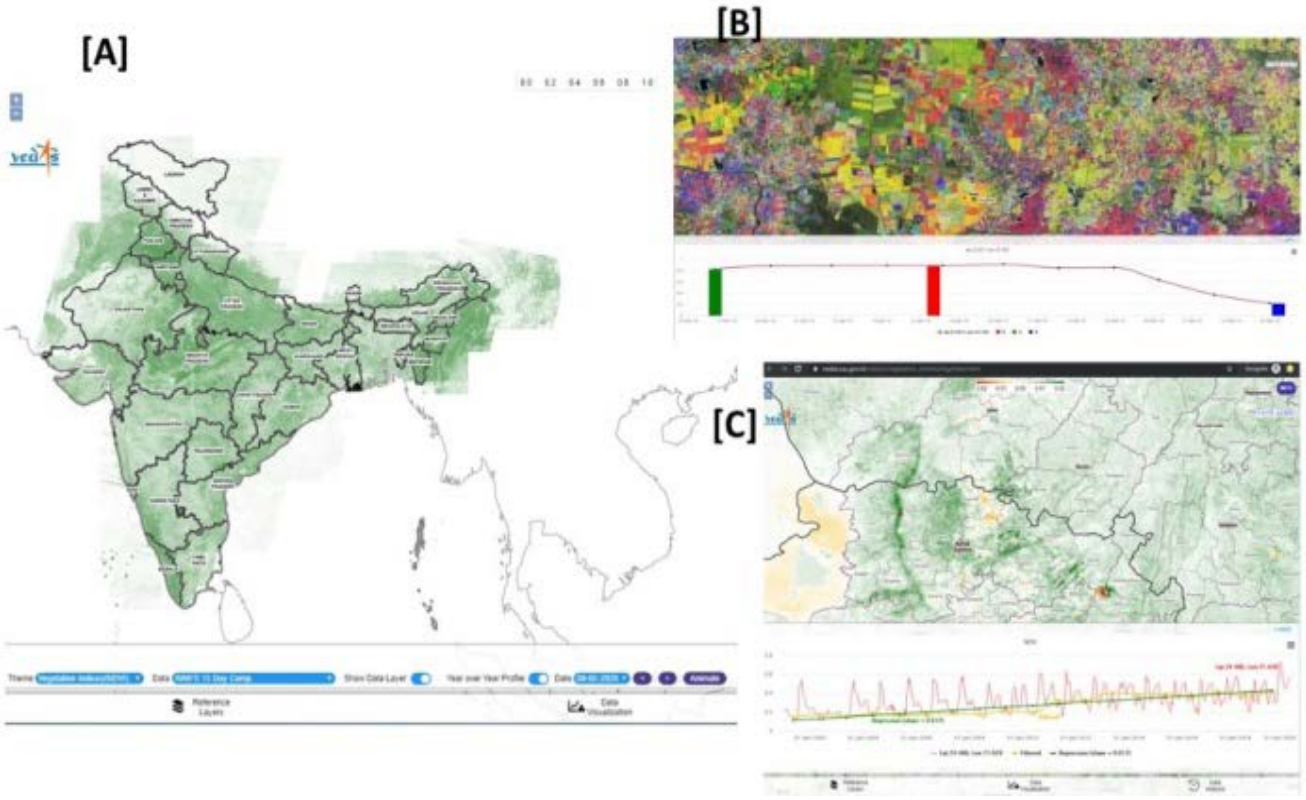


Fig 15: *A (Top): All India max. NDVI for first fortnight of Feb. 2020; B (Top – right): Sentinel NDVI RGB for field level monitoring; C (Bottom - right): Long term trend [Greening around Canal is noticeable]*

As part of the efforts to develop satellite data based applications in the field of metrology and oceanography new applications were developed and released on Meteorological and Oceanographic Satellite Data Archival Centre (MOSDAC). Safe Beach application released on MOSDAC is first of its kind, where Rip current forecast based alerts are disseminated for 175 beaches of India. Web application for monitoring of Oil spills and its possible progression direction using Altimeter LCS-Cores and Stretching Directions is also developed and released. New State portal is developed for dissemination of forewarning and alerts. New Features are released on MOSDAC to strengthen analysis, visualization and dissemination, this includes MOSDAC LIVE: (https://mosdac.gov.in/live), this is a web based visualization and analysis system. Three Doppler Weather Radar data (TERLS, Cherrapunji, SriHarikota) are disseminated from MOSDAC. An e-mail based dissemination of ocean forecast is made operational at MOSDAC and regularly these forecast are sent to registered ships in fully automated mode.

Contact detail: Director, SAC Email: director@sac.gov.in

NATIONAL REMOTE SENSING CENTRE
HYDERABAD

National Remote Sensing Centre (NRSC) is the major centre of ISRO, at which remote sensing data from Indian satellites are downloaded, processed and disseminated.

A. MAJOR FACILITIES / INSTRUMENTATION Developed:

- **NAS STORAGE SYSTEM:**

NAS storage system has been augmented with 100 TB of Fast high speed SSD Storage and 200 TB of NL- SAS Storage over the earlier existing capacity of 100 TB storage to meet the data storage space requirements as a centralized facility.

- **ARCHIVAL OBJECT STORAGE SYSTEM:**

For systematic archival of voluminous geospatial and non-spatial raw/ processed/ final/common reference data sets, the central facility is augmented with an Object Storage System with 800TB storage capacity, which supports the storage, indexing, query and retrieval of objects at scale with metadata, access control lists and preservation policies. It has unlimited scalability unlike conventional NAS file systems. This is advantageous in terms of its data protection, discovery, retrieval, sharing and collaborative workflows built upon cloud technologies.

B. SCIENTIFIC/APPLICATION RESULTS

Remote sensing applications through synergistic use of earth observation, communication & navigation satellites and complemented with ground based observations is applied for harnessing the benefits of space technology for food and water security, sustainable development, disaster risk reduction and efficient governance in tune with national and global commitments towards UN-2030 Sustainable Development Goals.

The major contributions in the area of remote sensing of Earth's resources for the years 2018 and 2019 have been towards adopting state of art satellite data and technologies to generate multi-level (scale) geospatial solutions in the fields of agriculture, forestry, water, rural & urban development, geodynamics, mineral resources and disaster management. Some of the remote sensing applications are provided below :

- **Locust Surveillance Using Geospatial Technology**

The Locust Surveillance study has been initiated using the space-borne data. Cyclones like Sagar, Mekunu and Luban brought heavy rains in the Empty Quarter of the Arabian Peninsula during the year 2018, and have favored the ecological conditions to exacerbate the Desert locust outbreaks. FAO alerted Locust Upsurge 2019-2020.

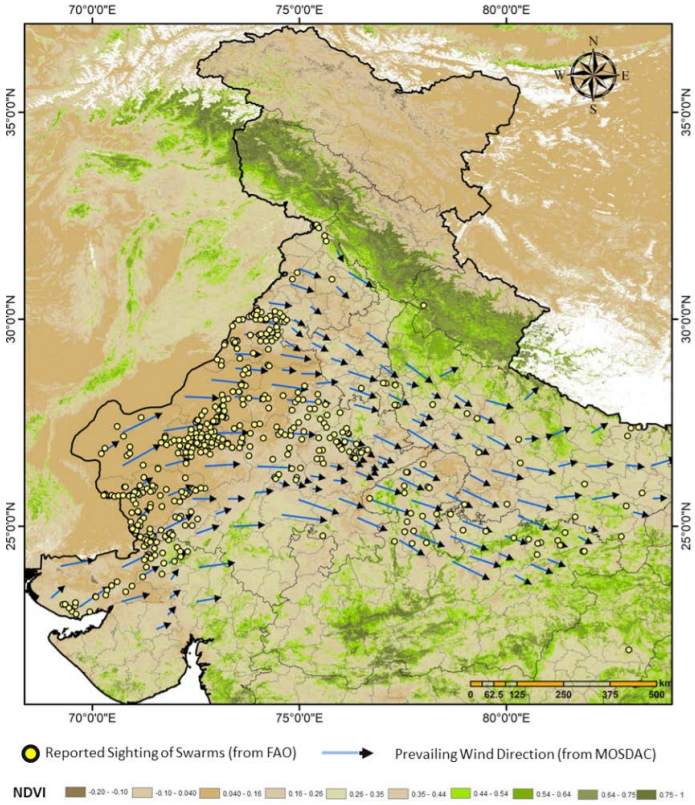


Fig 1: *Prevailing wind direction, locations of Locust swarms, and vegetation status as on 28thJune 2020. The environmental conditions have influenced the Locust migration towards Nepal on 30th June 2020*

The situation of locust swarm migration has been intensified during Amphan cyclone in the Bay of Bengal and led the trajectories of migration to most parts of the countries. RRSC-W, Jodhpur has effectively utilized multi-platform and multi-sensor satellite data from various open source platforms like MOSDAC, Bhuvan and others. Starting from May, 2020 to till date RRSC-W has released 17 bulletins which encapsulated the below topics.

- Results of heuristic prediction of locust swarm trajectory based on vegetation status, wind parameters and existing geolocations of locust swarms.
- Maps of wind parameters (speed and direction), soil moisture (root zone and sub-surface), accumulated rainfall, land surface temperature, FCC, NDVI data and etc.
- Alerts / Locust impact results / crop loss analysis
- Knowledge base (like climate and locust relation, understanding the locust behavior and life cycle events, etc.)

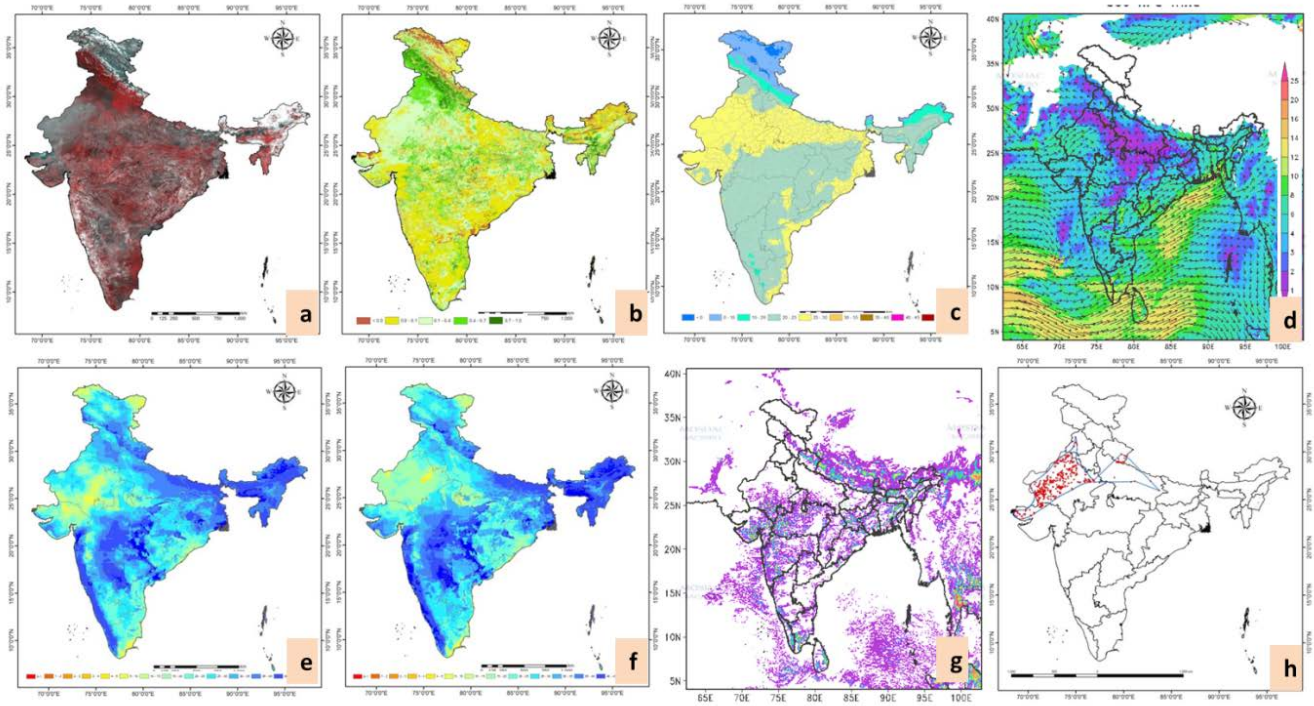


Fig 2: *Integrated set of various remote sensing data used for heuristic prediction of Locust and to generate Locust threat maps. (a) False color composite, (b) Normalized difference vegetation index, (c) land surface temperature, (d) wind vectors, (e) Surface soil moisture, (f) Root-zone soil moisture, (g) accumulated rainfall, (h) points of existing Locust provided by LWO/FAO.*

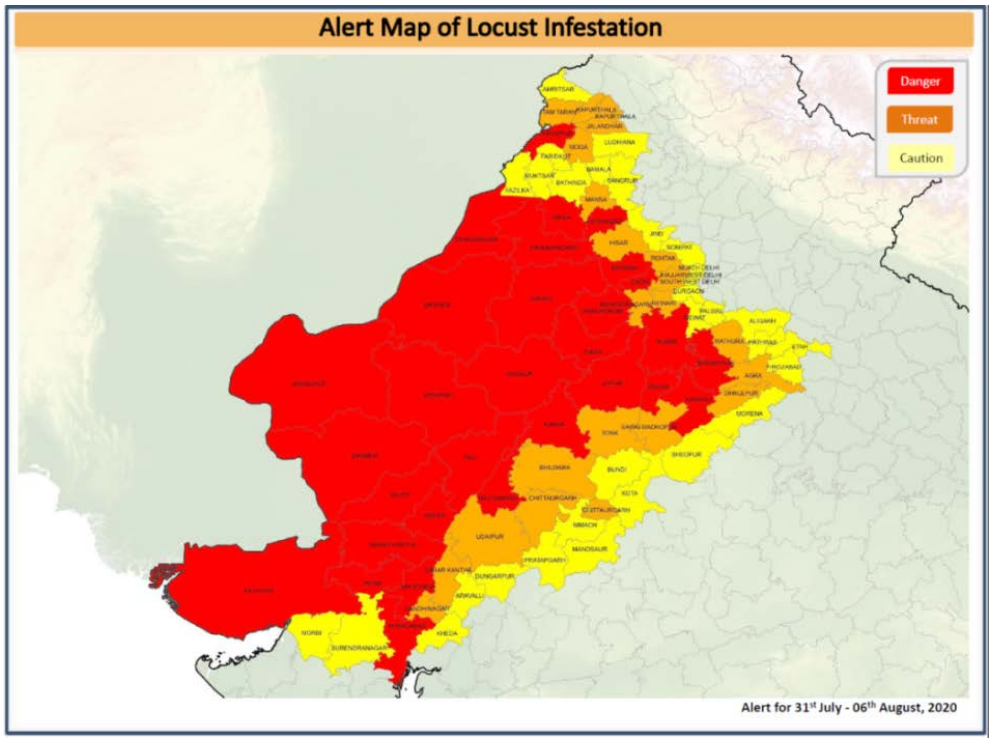


Fig 3: *District-wise Locust Alert Map*

Along with the Locust Warning Organization (LWO), Jodhpur (the main stake-holder having highest techno-potential to use these datasets) the bulletin has wide circulation including Indian Agricultural Research Institute (IARI), state agriculture universities, state remote sensing centers and allied departments. RRSC-W, Jodhpur has developed 'Bhuvan-Tiddi' mobile app (on the guidelines of FAO field collection methods) which was a customized variation that suits the field level officials of LWO and also supports citizen reporting. A dedicated web portal titled 'Bhuvan-Locust' has been designed, developed and about to host in Bhuvan regional node at RRSC-West.

- **INVENTORY OF HORTICULTURE CROPS**

The inventory of major horticulture crops (mango, banana and citrus) under the Co-ordinated Programme on Horticulture Assessment and Management using GeoiNformatics (CHAMAN) project is being carried out.

The multispectral data from LISS-IV and Cartosat-1 panchromatic data along with NDVI image was used as source data for segmentation and seven image features namely mean spectral values, NDVI, Brightness, SD, homogeneity, shape index and area were used for classification of orchards using Support Vector Machine. Project is executed for Department of Agriculture, Cooperation & Farmers Welfare, GOI. Project was initiated to realize the potential applications of geospatial technology for inventory of horticultural crops.

Fig 4. *Horticulture Inventory*

- **CROP INSURANCE STUDIES**

Scientifically proficient and transparent crop insurance mechanism has been demonstrated by complementing Earth Observation data with other state of art geospatial tools, field instrumentation and analytics covering complete value chain of the crop insurance framework.

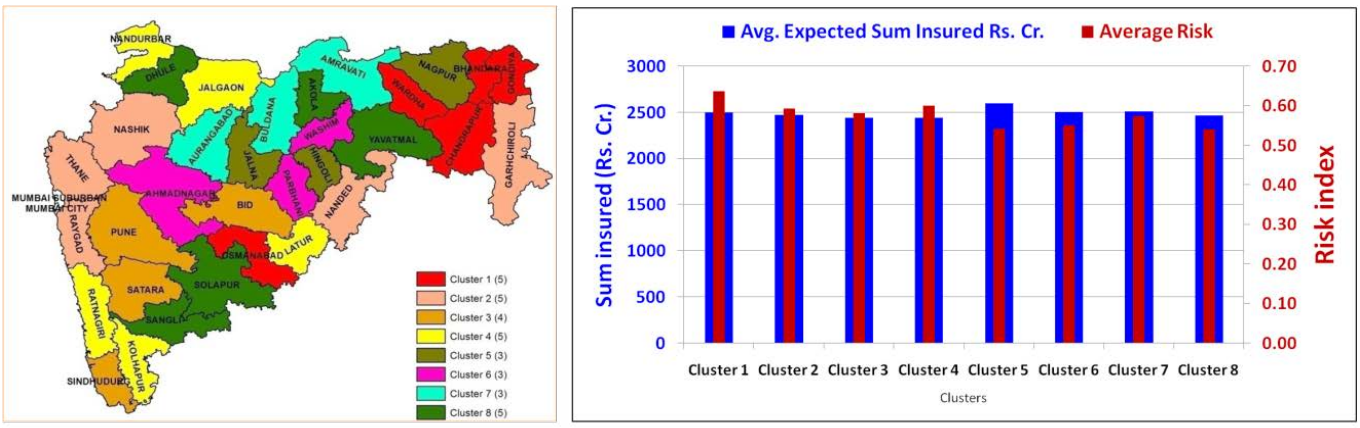


Fig 5: *Agriculture Risk Index*

- **CROP RESIDUE – SCOPE FOR BIOMASS BASED ENERGY GENERATION**

Spatial Information System - BHUVAN JAIVO ORJA has been developed to demonstrate the scope of biomass based energy generation and informed decision making factoring availability of crop residues, existing land use and logistics locations (transport and industries)

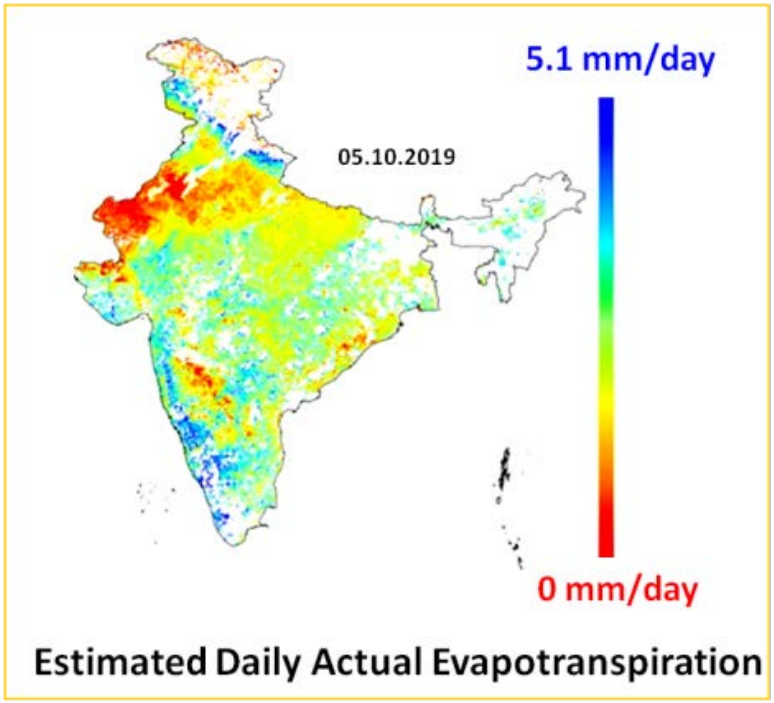


Fig 6: *Estiamted Daily AET*

EO based operational Hydrological Products

Earth Observation based operational Hydrological Products (viz., soil moisture, surface runoff, Evapotranspiration and Surface/River water, elevation) along with computational hydrological modelling frame work has been developed for generating daily near real time Actual

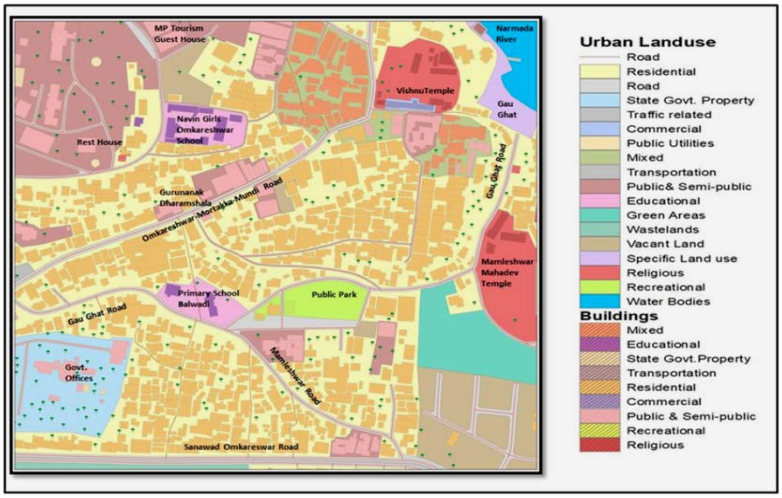
Evapotranspiration (AET) products (Fig 6) to re-assess country's water availability at present time-scale

- **FOREST & ECOLOGY**

ANALYSIS OF FOREST COVER LOSS Automated methods involving rapid processing and analysis of temporal EO data were developed to detect and characterize gross deforestation i.e., the loss in forest area over annual time periods caused by conversion of forest to non-forested land.

FOREST FIRE ALERTS EO data analytics based fire production chain is operational to generate and disseminate forest fire alerts to the user departments (MoEFCC/FSI and state forest departments). Besides, indices based techniques are developed to map burnt areas of forests using temporal stacks of EO datasets, which can be useful in providing Information about actual area burnt in an episode of forest fire.

CARBON STUDIES: As part of terrestrial carbon studies, efforts to assess vegetation (forest) carbon pools and fluxes over representative forest ecosystems across India are being continued in support to national activity under National Communication to UNFCCC. In addition, Terrestrial LiDAR based Non-Destructive Tree volume estimation techniques are being developed for Biomass estimation. EO based strategies are being developed for monitoring biodiversity at the community level in India focussing on decadal changes to the regional forest landscape, characterization of vegetation communities and web-based data repository.



AMRUT Urban GIS Database for Part of Omkareshwar on 1:4,000 scale – Input to Master Plan Preparation

Fig 7.

- **URBAN PLANNING**

Generation of town wise urban geospatial databases for 241 Class-1 cities (Cities having population > 1lakh) from 21 states / Union Territories on 1:4,000 scale using Very High Resolution

Satellite (VHRS) data for formulation of GIS based Master Plans. Besides, Land Use was created on 1:50,000 scale using EO data of 2016-17 for the adjoining regions of Delhi to facilitate revision of Regional Plan of National Capital Region – 2021.

RURAL DEVELOPMENT - GEO-GOVERNANCE BASED MOBILE APPLICATIONS

- Supporting host of applications in rural as well as urban development are developed and shared with the stakeholders. These are complemented with the web based solutions to ensure last mile delivery of the earth observation based services.
- Geo-MGNREGA web interface providing information on rural assets creation under the world's biggest social safety net is being supported in three stages i.e. before, during and after; to ensure highest level of transparency and accountability based on EO data. Geo-web enabled portalfor NRM based planning at village level is being developed using space based and multi-thematic inputs at 1:10,000 scale.
- High resolution satellite data (both multi-spectral and panchromatic) is conjunctively used to support watershed development (planning, development, and implementation monitoring and impact assessment) in the country.
- Land use/land cover change trajectories are captured for selected hotspots in the country (2006-15) using time-series High Resolution satellite data sets.

GEOSCIENCES

- Development of techniques based on geological, geophysical and spectroscopy signatures analyses for exploration of minerals like Diamond, Iron, Manganese, Rock Phosphate, Gold and clay is in progress.
- Shallow aquifer studies, especially saline and fresh water interface for the coastal aquifer is being studied using GPR and high resolution data sets.
- Planetary sciences: Hyperspectral data is used for the terrestrial analogue of MARS especially to understand the Martian mineralogy & space based weathering process.

• DISASTER MANAGEMENT SUPPORT (DMSP)

Continuous near real-time monitoring of cyclone and flood events, value addition like infrastructure damage is operational. Flood hazard zonation map has been prepared for Odisha State (Fig 9). National Database for Emergency Management (NDEM) has achieved structured multi scale geospatial database for entire country with historical repository of the natural disasters specific products. Development of operational and fully automated web-enabled spatial flood early warning models for few major Indian Rivers are in progress.

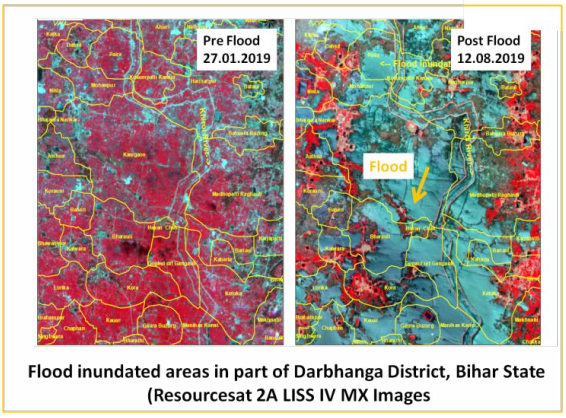


Fig 8. *Real time monitoring of flood*

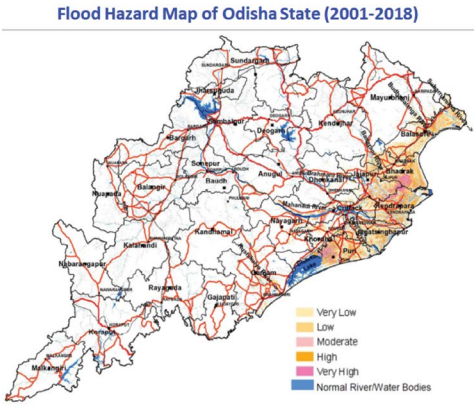


Fig 9. *Flood zonation atlas*

- **EARTH'S ATMOSPHERE AND CLIMATE**

Earth and Climate Science Area focused on wide variety of basic and applied research primarily related to climate studies.

CLIMATE IMPACTS OF AEROSOLS OVER HIMALAYAS:

Long term trends of absorbing aerosols were estimated to understand the climate impact of absorbing aerosols over Himalayas, using available satellite data (2006-2016) and reanalysis data for a period of 39 years (1980-2018). Significant positive trends of Black Carbon aerosols at surface level are observed over the Indo-Gangetic Plain, especially over its eastern parts, with a rate of increase as high as 80ng/m3/year. Central Himalayas experience higher concentration of elevated aerosols and aerosols over Himalayas at higher altitudes are significantly contributed by dust particles, which are transported from the arid continental regions. Presence of elevated aerosols with considerable fraction of dust over Himalayan regions would have significant impacts on regional climate. In addition, during the Smog conditions over Delhi and adjoining areas due to agricultural residue burning in November period; AOD and CO concentrations were enhanced by a factor of 4 and 1.2 respectively.

DAY-AHEAD FORECAST OF SOLAR ENERGY

A methodology for estimation of day-head forecast of surface reaching solar radiation at 15min interval by injecting the various satellite retrieved parameters into a forecast model has been developed, validated and technology was transferred to NTPC

LIGHTNING DETECTION

Understanding atmospheric lightning flashes and their occurrences is one of the most important aspects of the Earth's climate science. Real-time lightning data have profound importance in climate science, air-quality research and atmospheric nitrogen budget, apart from lightning being one of the major natural disasters. Keeping these in view, a lightning detection sensor (LDS) network is under development.

POLAR STUDIES

CO_2 and CH_4 measurements were carried out over Polar Regions. The average mixing ratios of CO_2 and CH_4 during the 37th Indian Scientific Expedition to Antarctica are found to be 399 ± 2 ppm and 1.8 ± 0.01 ppm during 2016-2017. Over Arctic, preliminary results indicate that arctic soil is acting as source and sink for CH_4 depending upon soil moisture and source for CO2. In addition; as part of 10th Southern Ocean Expedition (Dec 2017-Feb 2018); Bio-optical variability over Indian sectors over Southern Ocean and Antarctica coastal water were carried out using ground-based Bio-optical instruments in-conjunction with satellite data. It was observed that Deep Chlorophyll Maxima (DCM) is at subsurface cold water (~40-100m depths) sandwiched between two warm waters. An expedition to the Arctic was carried out during Aug-Sept, 2018 with an objective of characterizing Permafrost Degradation in Svalbard and its Impacts on Ecosystem. A site near the Ny-Alesund airport was identified for long-term monitoring for permafrost degradation due to natural as well as anthropogenic activities. Isotopic analyses of water samples are being carried out to identify signatures of permafrost thaw.

EFFECT OF CLIMATE CHANGE ON RIVER PARAMETERS: To understand the effect of climate change on river parameters; a methodology has been developed to compute the continuous width of the river waters from the satellite data. Systematic validation for various river types is in progress. Continuous widths computed for a segment of the river Ganges using automated satellite data based width computation tool.

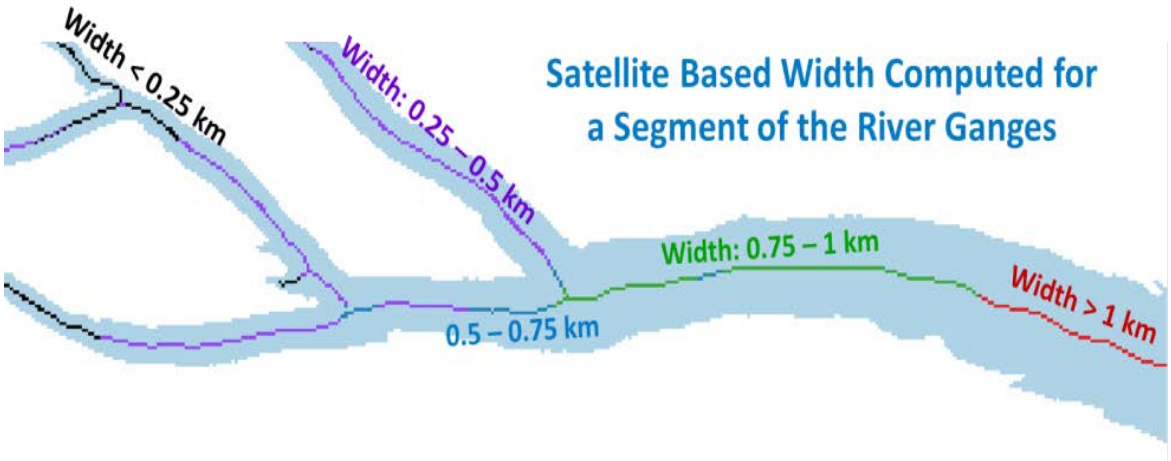


Fig 10: *Satellite based width computation*

STUDY ON GENESIS POTENTIAL PARAMETER USING SATELLITE DERIVED DAILY TROPICAL CYCLONE HEAT POTENTIAL FOR NORTH INDIAN OCEAN:

To estimate the cyclone genesis potential parameter using satellite derived daily Tropical Cyclone Heat Potential (TCHP) for North Indian Ocean; an analysis is carried out on 92 non-developing and 93 developing systems. It was observed that the average TCHP is 89.3 kJ/cm2 for developing systems at the day of formation of depression, while average TCHP is 78.3 kJ/cm2 for non-

developing system in north Indian ocean. Using daily TCHP, Genesis Potential Parameter and Genesis Potential Index parameters; the study shows that both are better predictor for less than 2 day lead period, while for more than 2 days, the distinction becomes difficult.

CARBON CYCLE MODELLING & SIMULATION:

An atmospheric transport model (GEOS-CHEM) has been implemented to study the variability of atmospheric CO2 over Indian region. Seasonal variability of atmospheric CO2 show that the regions with high values (April to May) are primarily located in the northern (north of 15°N) and north-eastern parts of India than in the southern regions of India. The northern part of India exhibits a distinct bi-annual oscillation while the southern peninsular India exhibits dominance of annual oscillation. At the annual scale, the atmosphere surface layer shows a net gain of 0.89 ppmv/ yr (0.38 ppmv /yr) for the north (south) India which is one third of the surface fluxes. This implies that most of the surface emission is transported out from the surface layer of the atmosphere over India.

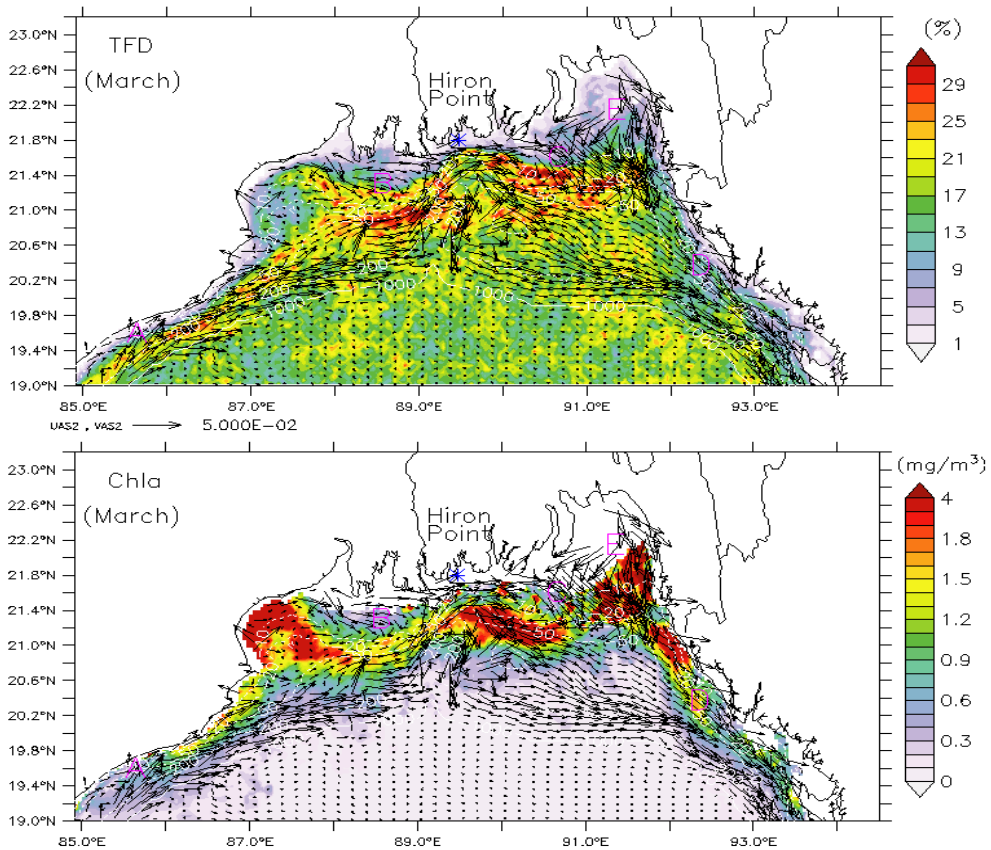


Fig 11: *The top panel shows mean circulation patters (vector) based on simulated currents and TFD (colour) for the month of March 2014. Bathymetry contours of 10 m, 20 m, 50 m, 200 m and 1000 m are overlaid (white). The bottom panel shows the residual circulation (vector) overlaid on the Chla (colour) image.*

PERSISTENCE OF THERMAL FRONT AND CHLOROPHYLL-A AND THEIR SEASONAL CYCLE IN THE NORTHERN BAY OF BENGAL:

A study on the persistence of thermal front, chlorophyll-a, and their seasonal cycle in the northern Bay of Bengal was carried out using time series of daily Sea Surface Temperature (SST) and weekly chlorophyll-a data. Both data are highly coherent and persistent at the seasonal cycle with maxima occurring between 10 and 50 m isobaths in the northern continental shelf region, and along the shelf break on the south western flank of the study region. The seasonal cycle accounts for 80% of the total variability of the TFD time series. The peak values of TFD are occurring in November and lasts up to March. The regions of high persistent TFD have high abundances of chlorophyll-a concentration and productivity. All these informations together established the fact that this region is highly persistent in terms of thermal fronts and productivity and can be considered as a potential fishing zone.

NATIONAL INFORMATION SYSTEM FOR CLIMATE AND ENVIRONMENT STUDIES (NICES):

NICES is an area where a sustained progress is made in terms of generation and dissemination of climate data products. Currently, 64 bio-geophysical products are being generated using satellite data and out of which 13 are qualified to be Essential Climate Variables (ECVs) as per GCOS standards. These bio-geophysical products are being disseminated through ISRO's geo-portal called 'Bhuvan' to users engaged in climate change studies and for various applications. Also, several regional workshops were conducted to promote wider utilization of NICES bio-geo-physical products and effective collaboration with the academia towards research and development. Towards validation of retrieved products, various ground-based instruments have been established at multiple locations and collected oceanography parameters data by participating national scientific cruises and international scientific expeditions.

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NORTH EASTERN SPACE APPLICATIONS CENTRE
SHILLONG, MEGHALAYA

North Eastern Space Applications Centre (NESAC) was established in the year 2000 as an autonomous organization under Department of Space, Government of India with an objective to cater to the needs of space technology inputs for the development of the north eastern region (NER) of India. The major objectives of the centre are (i) to provide an operational remote sensing (RS) and geographic information system (GIS) aided natural resource information base to support activities on development and management of natural resources, infrastructure planning, and governance in the region, (ii) to provide operational satellite communication applications services in education, health care, disaster management support, and developmental communication, (iii) to take up research in space and atmospheric science area and establish an regional instrumentation facility and networking with various academic institutions, (v) to enable single window delivery of all possible space based support for disaster management, and (vi) to set up a regional level infrastructure for capacity building in the field of geospatial technology.

A. Summary of overall activities

NESAC has witnessed significant growth in multiple areas of its activity during last two years. While satellite based RS and GIS applications remained the core area of activities, newer technologies like unmanned aerial vehicle (UAV) based RS, application of artificial intelligence (AI) for different thematic applications, etc proved their potentials for future applications. NESAC has also made its presence felt through a wide range of capacity building initiatives and set up an integrated facility for training and research. The use of space technology applications by various state government agencies for development planning and governance got major boost during this time. The centre completed more than 20 projects during this time and more than 50 projects are ongoing. A high end Graphical Processing Unit, UAV based hyper-spectral camera, cloud condensation nuclei counter, etc. have been procured. Networks of lightning detectors and river discharge monitoring stations have been set up and the network of automatic weather stations has been augmented with 21 more stations. NESAC also received two awards, the eNorth East award 2019-2020 and the Lightning Resilience award.

NESAC completed the national project on identification of potential areas for expansion of sericulture in Phase-I and Phase-II, RS and GIS inputs for preparation of forest working plan in Arunachal Pradesh, and forest growing stock assessment for preparation of forest working plan in Mizoram. A north eastern spatial data repository (NeSDR) with large number of spatial data on NER has been implemented that facilitates users to visualize, retrieve, geo-process and publish geospatial layers. The Election e-Atlas developed by NESAC was successfully utilized during the Lok Sabha Election, 2019 in the states of Manipur, Tripura, Sikkim, Nagaland, Meghalaya, and Mizoram. NESAC has also successfully demonstrated the application of UAV and satellite RS for geo-tagging and monitoring of government funded projects/schemes in NER. NESAC has also

demonstrated some unique applications such as tethered UAV for dropping of medicine, food and relief material at the time of disaster, spraying of pesticides in agricultural field using UAV, application of AI for RS data processing, etc. The Flood Early Warning System (FLEWS) program has been expanded to all NE states with an average success score of 75% and an average alert lead time of 24 to 36 hours. NESAC also developed a location based lightning early warning system by successfully assimilating the real time lightning information in numerical models.

B. Infrastructure created during 2018-2020

The following infrastructure have been created during the reporting time

- An integrated outreach facility with state-of-the art class rooms, laboratories, hostels, and recreation facility has been created for national and international level training.
- A high end Graphical Processing Unit (GPU) server has been procured to support AI related activities.
- One aerosol observatory with several instruments for optical and physical characterization of aerosol has been set up at Lachung, Sikkim.
- A tethred balloon facility to lift 7-8 kg of payloads has been established.
- 21 AWS has been installed and process initiated for 18 more procurements.
- Six river discharge gauge has been established.
- A network of six Lightning detectors have been set up
- A Cloud Condensation Nuclei (CCN) Counter procured to initiate aerosol-cloud interaction studies
- A 3D printer has been installed at NESAC

C. Science Research and Application

- **Remote sensing of Earth's resources and environment**

The major activities in this area during the reporting period are the following:

- NESAC has been implementing a major project on Sericulture development sponsored by the Central Silk Board (CSB), Ministry of Textiles. Under this project potential areas are being identified for expansion of sericulture. The second phase of the project covering 70 priority districts from 26 states has been concluded with organization of a national workshop at NESAC during Aug 5-6, 2019 where the project atlas and the SILKS portal (www.silks.csb.gov.in) developed as a part of the project were released to all the concerned stakeholders. A new project on geo-tagging of assets created by CSB in NER has also been initiated.

- The first phase of the CHAMAN (coordinated horticulture assessment and management using geo-informatics) project work for NER on mapping of areas for expansion of one horticultural crop in one district has successfully been completed. The second phase of project covering 16 districts of NER is being carried out. There were significant progress for a number of other projects in Agriculture and allied areas, such as acreage estimation of selected crops and development of a mobile app for planning and monitoring of crop cutting experiments in Meghalaya, Maize area and production estimation in NER under SUFALAM programme, identification of block level winter rice areas in Meghalaya, mapping of district wise soil fertility status of Meghalaya, desertification and land degradation monitoring, vulnerability assessment in six states of NER and West Bengal, etc.
- In the area of remote sensing applications in Forestry, NESAC has been carrying out different projects like RS and GIS inputs for preparation of forest working plan in Arunachal Pradesh, Forest growing stock assessment for preparation of forest working plan in Mizoram, geospatial assessment of forest fire in different forest divisions of Manipur, jhum area mapping and monitoring in malaria prone Dhalai district of Tripura, analysis of vegetation phenology of NER, Land cover dynamics of Kaziranga national park, SAR (Synthetic Aperture Radar) applications in the estimation of above-ground biomass in forests of NER, etc.
- In the area of hydrology & water resources, flood early warning system (FLEWS) program has been expanded to all NER states. An average success score of 75% and an average alert lead time of 24 to 36 hours could be achieved for the flood warnings under the FLEWS programme for flood-prone districts of Assam. Preparation of Assam river atlas covering the entire Brahmaputra and Barak basin has been completed and monitoring and evaluation of integrated watershed management program for NE India are also in progress.
- As part of urban and infrastructure planning, the centre has been supporting in formulation of GIS-based master plan and development plans, Atal mission for rejuvenation and urban transformation (AMRUT) sub schemes. Several other studies being carried out by the group are GIS based approach towards assessment of traffic congestion in Kohima city, border area development plan, Creation of geo-spatial database of jhum cultivation in Meghalaya, etc.
- In the area of Geosciences, NESAC has carried out a number important studies including GPS based total electron content studies for earthquake precursors, Morphotectonics, Neotectonic and deformation studies, Ground water quality mapping, environmental and technological hazards assessment, river dynamics and erosions of Manas-Beki river, etc.
- In the area of information technology & geoinformatics, one of the major programmes completed is creation of north eastern spatial data repository (NeSDR) with thematic layered database for the entire NER to support governance and planning. The Election e-ATLAS developed by NESAC was successfully utilized during the general Lok Sabha Election, 2019 in the states of Manipur, Tripura, Sikkim, Nagaland, Meghalaya, and Mizoram. Several other major projects such as Mobile-based integrated surveillance system for early diagnosis &

treatment of Malaria and other diseases, geo-tagging and monitoring of government funded projects/schemes in NER are progressing well.

- NESAC has expanded its activities in the field of UAV remote sensing and applications. NESAC has demonstrated some unique applications such as tethered UAV for continuous surveillance, mechanism for dropping of medicine, food and relief material at the time of disaster, spray of pesticides using UAV, etc. Various research activities are presently carried out using UAVs are crop damage and stress detection, embankment survey & monitoring, survey and mapping of community reserves and other protected areas and their eco sensitive zones in Meghalaya, etc

- **Earth's atmosphere and climate**

The major activities and achievements in this area are described below:

- **Vertical profiling of absorbing aerosol:** Vertical profiling of absorbing aerosol over a mountainous terrain was done through conducting a campaign using tethered balloon and Microaethalometer**.** The vertical profiles of temperature, pressure, relative humidity, specific humidity and virtual potential temperature were observed to be in good agreement with the profiles of black carbon (BC) indicating the impact of atmospheric boundary layer (ABL) on BC variability. Smoke extinction coefficient measured by CALIOP payload onboard CALIPSO satellite for winter season (January and February) of 2019 matched well with the profile obtained using Microaethalometer.

Fig. 1: Hydrogen gas filled tethered balloon (left) and instrumented payload connected with the tethered balloon (right)

- **Aerosol characterization over eastern Himalayan regio**n: A high-altitude aerosol observatory has been established at Lachung (27.4° N, 88.4° E; 2650 m) in the eastern part of Himalayas, to study the physico-chemical and optical properties of aerosols using a suite of instruments. In addition, two more observatories at Umiam, Meghalaya and Tawang,

Arunachal Pradesh are also operated by NESAC. Biomass burning aerosols significantly influence the spectral absorption properties over Lachung, especially during winter. There is a marked distinction between the BC concentrations over the other two sites with Umiam dominated by large local sources of aerosols while Tawang dominated by transported aerosols from Brahmaputra valley. The columnar aerosol properties showed significant variation with wavelength over all sites which indicate changes in particle size and origin with season.

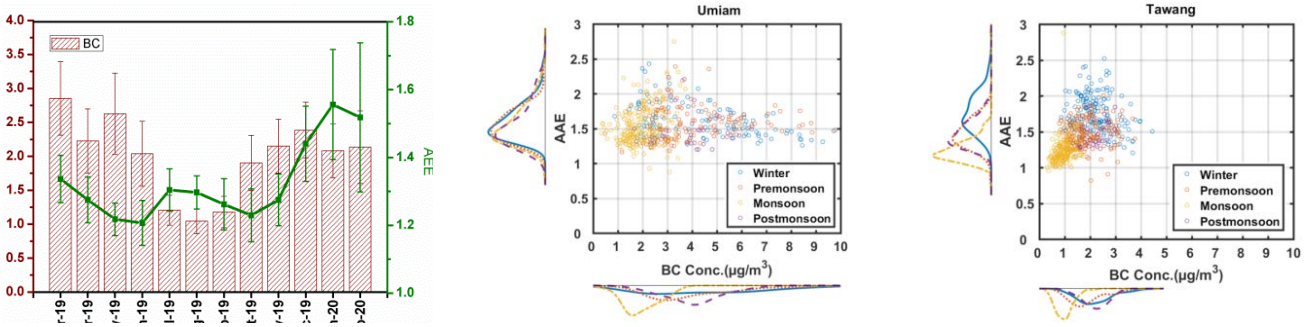

Fig. 2: Annual variation of BC aerosol and absorption Angstrom exponent over Lachung (left), scatter plot of BC against AAE along with their seasonal distributions as kernel density on the horizontal and vertical axes over Umiam (centre) & Tawang (right)

- **Study on cloud microphysical properties over a hilly station:** A cloud condensation nuclei (CCN) counter has been installed for measuring CCN concentration. Initial results suggest that mean CCN number concentration at 1% of super-saturation was 927±245 cm^{-3}, 1369±356 cm^{-3}, and 3922±1087 cm^{-3} during monsoon (June-Sept), post-monsoon (Oct-Nov), and winter (Dec) season respectively. CCN concentration is found maximum at night and minimum at daytime. Average value of the single hygroscopicity parameter (k), indicated abundance of hygroscopic particles during the post-monsoon season than monsoon.
- **Study of cloud base height over a complex topography:** A Ceilometer has been deployed at Umiam to collect continuous data on cloud base height (CBH) and ABL. There is a noticeable seasonal variation found in cloud occurrence frequency with maximum during July with a frequency of 61.95%. Clouds observed over Umiam are mostly of a single layer. The study was also continued to understand long term temporal change in cloud characteristics over NER of India especially during pre-monsoon season. It showed a decreasing trend in cloud base height over the western part of Brahmaputra river valley and southern states of NER namely Tripura and Mizoram during March, whereas Barak valley showed increase in the height.
- **Observation and analysis of Pre-monsoon weather system using polarimetric Doppler Weather Radar:** The dual polarimetric S-band Doppler weather radar (DWR) installed at Sohra (erstwhile Cherrapunjee), Meghalaya is used for real time weather monitoring and

for research in meteorology. The data is used for severe weather nowcasting, atmospheric science studies, aviation advisory, and also used by many user departments. The DWR data is also assimilated in weather research and forecasting (WRF) model to improve local scale nowcasting of severe weather.

- **Improving the short and medium range weather forecast using WRF model:** NESAC has been providing the short and medium range weather forecast over the NER of India using the WRF (weather research and forecasting) model. The forecast is provided for 48 hours for rainfall, temperature, and humidity at 9 km spatial resolution. The rainfall forecast is used by several users including for the FLEWS project covering large part of NER of India. Experiments have been conducted by assimilation the INSAT 3D radiance and wind data in the model for different case studies to improve the forecast.
- **Improving location based lightning nowcasting over NER of India** Probable lightning location maps are generated on hourly basis three times a day using numerical models. The forecast is compared with ground based lightning detector data and good agreement has been observed for lightning warning up to two hours lead time. The cyclone induced lightning was also studied to assess the inter-relationship between cyclonic intensity change and variation of lightning flash count.

Several other activities on Setting up a Hydro-Meteorological network in Arunachal Pradesh with 17 automatic weather stations (AWS) and four river discharge gauge to provide river discharge forecast for dam management in Ranganadi hydro electric project, similar project with six AWS and two river discharge gauge in Kopili basin, study on impact of meteorological parameters on Malaria epidemic in Ambassa region of Tripura, Assimilation of satellite based soil moisture in a land data assimilation system for investigating the spatio-temporal behavior of land-atmospheric interactions over India, etc has also made significant progress.

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INDIAN INSTITUTE OF SPACE SCIENCE AND TECHNOLOGY (IIST)
TRIVANDRUM

A. OVERVIEW OF SPACE RESEARCH ACTIVITIES

Between 2018 and 2019, the Indian Institute of Space Science and Technology (IIST) has achieved several notable milestones in the area of Space Sciences and Technology. The highlights of a few achievements are as follows. IIST developed a payload to study the ionosphere using the PS4 platform (which is 4th stage of PSLV launch vehicle) offered by ISRO, and the project was named ARIS (Advanced Retarding potential analyzer for Ionospheric Studies). This project generated significant interest in the institute and showcased faculty, students, and staff's ability to envisage, design, develop, and realize a payload in a short period. The IIST inhouse cubesat AHAN and INSPIREsat1 project with the Laboratory of Atmospheric and Space Physics, University of Colorado, Boulder has made significant progress during this period. With the ensuing opportunities in the Human Space Program (HSP), IIST has initiated research and academic activities in the broad area of Bioastronautics with a long term goal of capacity building in Space Biosciences. An interdepartmental elective course on astrobiology was introduced in the CBCS elective stream and was well received by BTech students. Additionally, IIST and the University of Cambridge had proposed for a space telescope ExoWorlds, designed to study the atmosphere of exoplanets.

Other highlights during the aforementioned period are as follows

- Radio observations of the electromagnetic counterpart of the first binary neutron star merger.
- The first detection of a supernova remnant in the star forming complex G351.7-1.2
- Accretion dynamics around Galactic black-hole sources particularly using Indian multi-wavelength mission Astrosat.
- Developed advanced mathematical techniques for modelling of tropical cyclones by incorporating satellite observations.
- Initiated work on a developing a re-analysis system for understanding the Martian/Venusian atmosphere.
- A baseline inventory of the mangroves of the entire coast of Maharashtra using sub-meter resolution is generated using multispectral satellite data.
- Developed an atmospheric correction module for hyperspectral remote sensing data.
- Analyzed the geological processes of Moon and Mars using planetary data sets of various space missions.

B. MAJOR FACILITIES/INSTRUMENTATION DEVELOPED

In the year 2018 – 2019, IIST developed a payload to study ionosphere using the PS4 platform offered by ISRO and the project was named **ARIS** (Advanced Retarding potential analyser for Ionospheric Studies). The ARIS measured the prevailing plasma parameters in the ionosphere launched on the PS4 operational platform on PSLV C45. This project generated significant interest in the Institute and showcased the capability of faculty, students and staff to envisage, design, develop and realize a payload in a short period of time. The highlight of the project is that it is the first ever space mission of IIST and achieved better than expected performance and it is a complete in house knowhow and development.

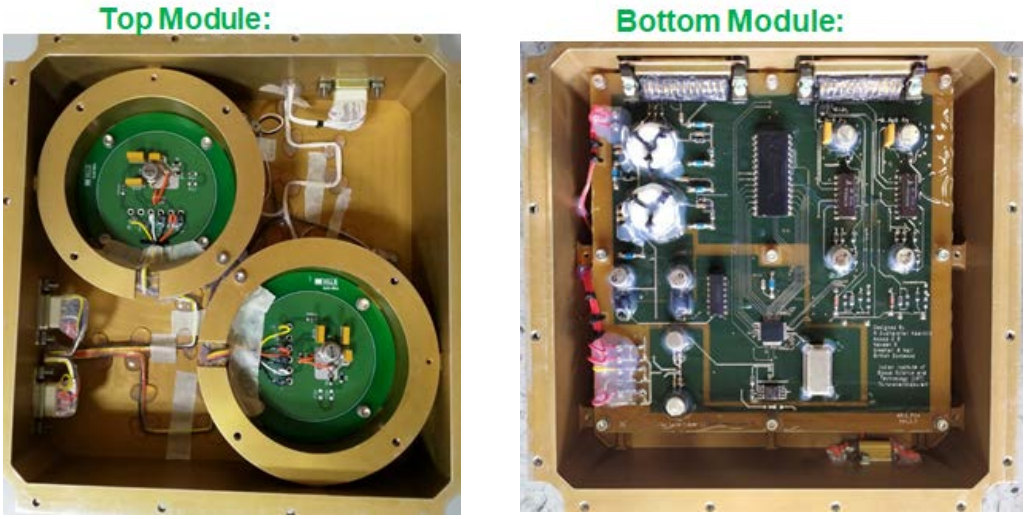

Fig 1: *Different parts (top and bottom modules) of the ARIS payload, assembled with the retarding potential analyzer and associated electronic printed circuit boards*

The INSPIRE satellite project with the University of Colorado are a few notable steps in this direction. The flight versions of the On Board Computer (OBC) and the Electrical Power System (EPS) designed by IIST were successfully integrated into the satellite. As part of AAReST project (now suspended) IIST developed mirrorsat structures, OBC, EPS , Attitude determination and control system (ADCS) with Y-momentum wheel and cold gas butane propulsion system.

Major Outcomes:

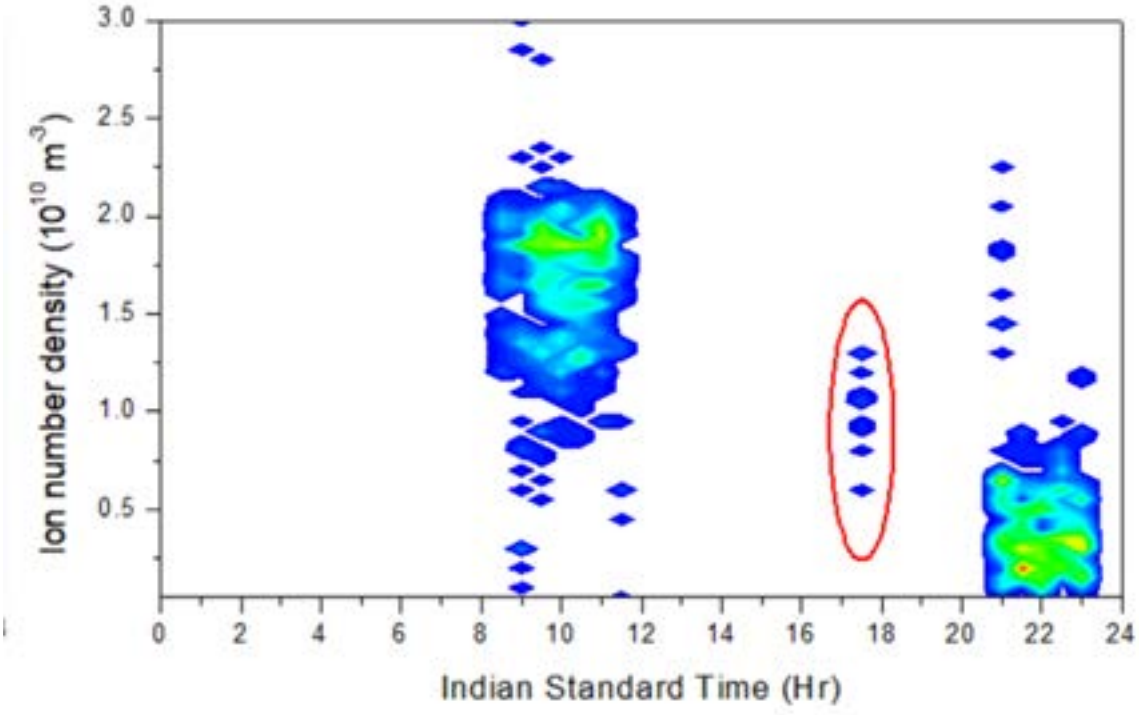

Fig 2: *Plot of the ion-density distribution of the earth ionosphere, obtained from the data given by the ARIS payload.*

Furthermore, IIST as part of its responsibilities delivered one mirrorsat structure to University of Surrey, UK. Ahan mission is a 3U student **Cubesat was designed** and developed at IIST to study the radiation environment at LEO by using the Giger Muller counter as the payload. The subsystems including On board Computer (OBC), Electrical Power Systems (EPS), Sensor electronics for GM counter, passive ADCS, and structures have been indigenously designed and realised at IIST.

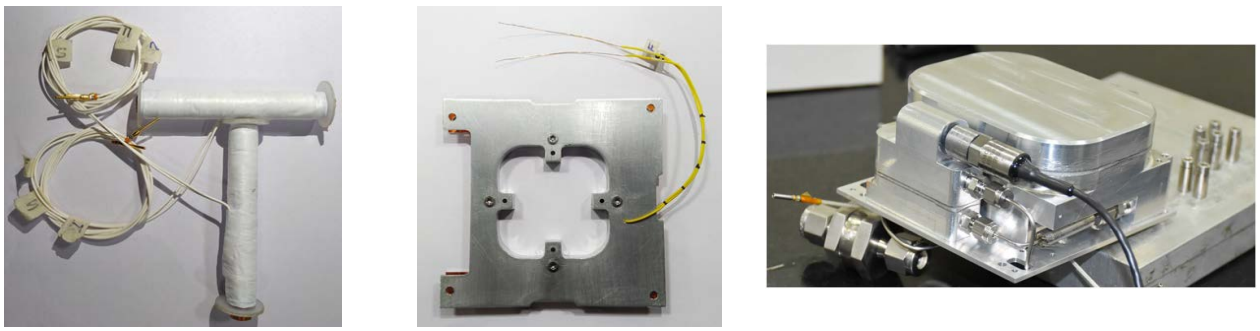

Fig 3: *Prototypes of Magneto torquer Metal core (left), Magneto torquer Air core (center), cold gas thruster (right)*

To summarize the following are the major facilities and space instruments were developed in IIST during the year 2018 – 2019.

1) Advanced Retarding Potential Analyser (ARIS) payload for LEO flown in PSLV C-45 mission.
2) Small Spacecraft Systems and Payload Center (SSPACE) electronics fabrication laboratory for design and development of small satellite subsystem
3) VHF/UHF Ground Station for LEO satellites

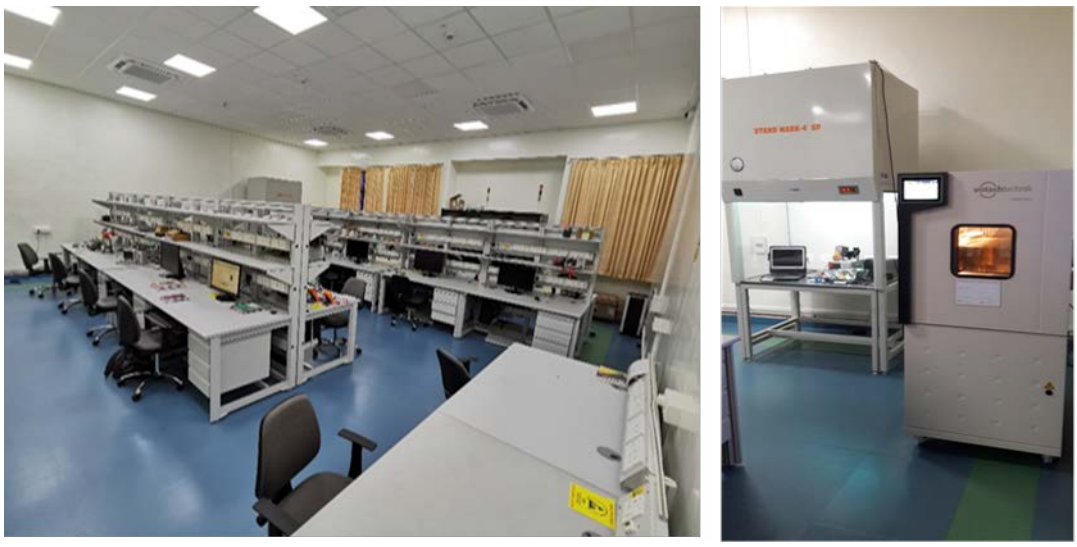

Fig 4: *Snapshots of SSPACE electronics fabrication lab*

Fig 5: **Ground Station Console** *(left image) and Ground Station Antennas VHF/UHF(right image)*

C. HUMAN SPACE FLIGHT PROGRAM (HSP)

The huge scope for Science and Technology development ensuing the announcement of Gaganyaan and subsequent HSPs, kindles the spirit of unique responsibility and reaffirms our critical roles in supporting the country's most prestigious organisation in achieving the mission objectives and carrying it forward. IIST marked a beginning in HSP related programs by identifying possible areas of research/academic contributions by discussing with the Directorate of HSP (DHSP), ISRO HQ.

IIST faculty submitted 12 proposals in 5 areas against the announcement of opportunity for microgravity science experiments. Among these, the project 'Spaceflight-induced changes in kidney stone formation in Drosophila Melanogaster has been recommended for the first development of Gaganyaan. An MoU between HSFC and IIST has been signed and the hardware development is in progress. As part of the project, basic facilities like incubator, stereo microscope and accessories to start space life science research using the Drosophila model have been procured. Further, TIFR-Mumbai has requested IIST to share the hardware for their space life science experiments and an MoU between IIST and TIFR-Mumbai is in the final stages of discussion.

- **Design and development of Gas Sensor for short and long term missions:**

An initiative has been taken by IIST to develop gas sensors (CH_4, CO, NH_3 and O_2) for upcoming HSP for which a low weight, high performance nanostructure gas sensor array on flexible substrate at room temperature where each element of the array will be functionalized by required nano materials (metal Oxide with catalyst) to enhance the performance of the sensor is being investigated. The group is actively involved with SAC-Ahmedabad and SCL -Chandigardh to develop a QM module of Gas sensors. The facility (figure 5) is equipped with three gas calibration set ups which are upgraded to multi gas calibration facility to calibrate the gas sensors in different environments. The facility is also having a material synthesis unit (nano materials) to develop gas sensors. The group is also trying to develop optical gas sensors for detecting multiple gases togethers for long term space missions.

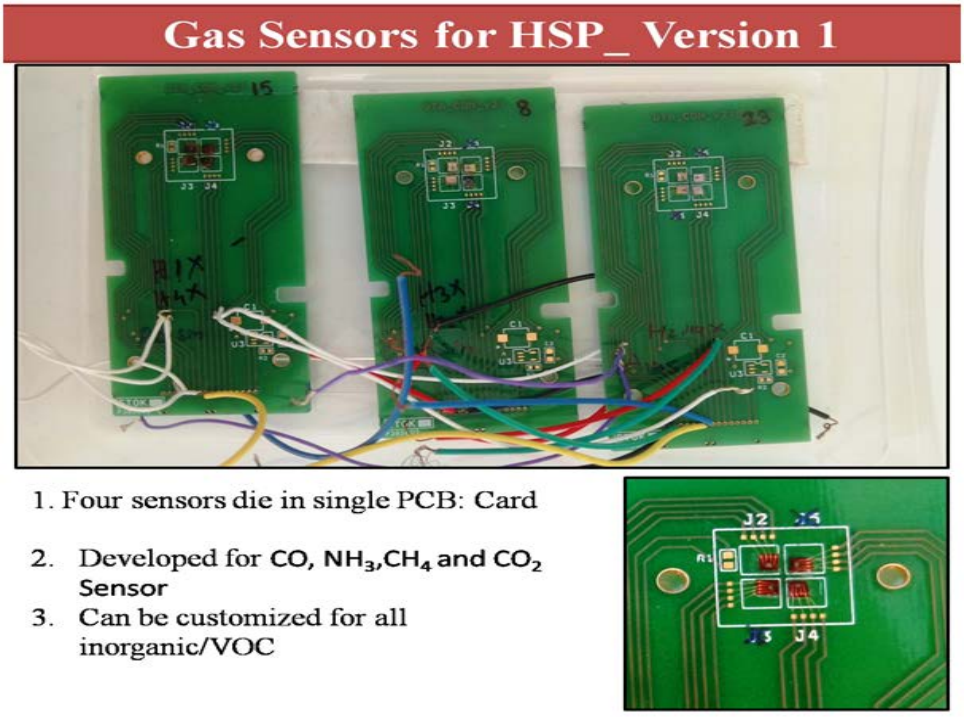

Fig 6: *First prototype of Gas sensors for HSP*

D. CATEGORY WISE SPACE RESEARCH ACTIVITIES AND MAJOR RESULTS

• Remote Sensing of Earth Resources and Environment

Mangroves are the evergreen forests that thrive in the brackish water environment of tropical and sub-tropical coasts. India harbors about 4900 sq.km of mangroves along the east and west coasts and in Andaman and Nicobar islands. On realization of the ecological and economical importance of the coastal forests, Maharashtra Forest Department has initiated Mangrove Foundation for the conservation and management of mangrove forests of the state extending for 448 sq.km. One of the activities of Mangrove foundation is to map and monitor the mangroves of the state which is taken up by IIST. IIST faculties are involved in the following development activities related to Mangrove foundation

(i) baseline inventory of the mangroves of the entire coast of Maharashtra using sub-meter resolution multispectral satellite data (WorldView 2/3).

(ii) Estimate the changes happened (new mangroves, degradation or conversion of mangroves to some other land use etc) over the period of nearly 14 years using large scale map earlier prepared for the year 2005 owned by the funding agency.

(iii) To periodically map the natural and anthropogenic driving factors causing the change in mangrove extent using open source satellite data – like NDVI, accretion, erosion, man made encroachment.

(iv) To deliver an application tool to derive mangrove health indicators using time series open satellite data.

In addition to these, the IIST faculties are conducting the following activities:

a. Development of atmospheric correction module for hyperspectral remote sensing data.

b. Integration of 3D laser scanning and imaging spectroscopy for mapping and monitoring of agricultural crops.

c. Spectral biochemical analysis of forest species using hyperspectral remote sensing.

d. Real-time remote sensing imagery processing system.

• Earth Atmosphere and Climate Science

The research in atmospheric science stream is mostly directed towards improving the tropical cyclone forecast over the Arabian Sea and the Bay of Bengal using satellite/remote sensing observations and atmospheric models. Mathematical methods have been developed to successfully incorporate satellite observations into the numerical weather forecast models to improve the tropical cyclone forecasts. The studies used observations from satellite sensors such as Advanced Microwave Sounding Unit (AMSU), High Resolution Infrared Sounder (HIRS-4), Microwave Humidity Sensor (MHS) etc. Further investigation is performed using ISRO's Scatterometer Satellite (SCATSAT-I)

and quantified its role in improving the Indian Summer Monsoon forecasts. IIST has established a Climate Observatory at its Ponmudi Campus. Many observational campaigns are carried out along with balloon launches to study atmospheric dynamics and meteorology.

- **Ionosphere, Magnetosphere and Solar-Terrestrial Relationship**

The studied are conducted by IIST faculties on the analysis of scintillation patterns, based on satellite spaced-receiver technique to estimate the zonal drift velocity of ionospheric irregularities. An ionospheric probe called Advanced Retarding potential analyzer (ARIS) is developed for measuring plasma parameters. The instrument was launched using PSLV C45 mission (as a PS4 payload) and it worked as expected and gave valuable information about the lower earth ionosphere.

- **The Solar System bodies including Planetary Science**

IIST and the University of Cambridge had proposed for a space telescope ExoWorlds, designed to study the atmosphere of exoplanets. IIST hosted the ExoWorlds Team Meeting from January 4 to 6, 2019, which had around 40 participants including two from University of Cambridge and from various Indian Institutes. The ExoWorlds mission is expected to make major scientific breakthroughs in Exoplanet science and to bring India in the forefront of this emerging field.

Research is initiated on exploring the scientific aspects of planetary atmospheres, which is aligned in the direction of ISRO's ongoing interplanetary missions. IIST is actively involved in the research on investigating the geological processes of Moon and Mars. The studies on the Grimaldi basin of the Moon has identified distinct phases of mare volcanism on the Moon, around 3.3 Ga, 2.05 Ga, and about 1.2 Ga, with the basalts distinct in composition and indicated an evolutionary history of the basin. Spectral analysis of data from Mare Humorum on Moon has enabled us to distinguish two chemical classes of pyroxenes, the formation of which could be connected to different magma cooling rates. Shifts in two characteristic absorption bands are considered as indicators of chemical variation of the pyroxenes. The pyroxene chemistry and ages of the basaltic units in the Mare Humorum have demonstrated a relationship on the time evolution of the basaltic magma.

Valles Marineris, the largest canyon of the solar system, is a morphological feature on the surface of Mars, which has drawn significant scientific attention in terms of its origin and evolution. Orbital remote sensing data from Mars Color Camera (MCC) onboard ISRO's MarsOrbiter Mission (MOM-1), Context Camera (CTX), High-Resolution Imaging Science Experiment (HiRISE), and Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) hyperspectral data aboard NASA's Mars Reconnaissance Orbiter (MRO) have been utilized to understand the role of various geological processes involved in the formation and evolution of Valles Marineris. Evidences for glacial and fluvial processes were identified from the Eos Chaos region of eastern Valles Marineris. A proposed model envisages the existence of an unknown volume of icy materials in

the subsurface of Mars, at least near the margin of Eos Chaos. It is also postulated that various valley systems around Eos Chasma, such as Osuga Valles, Tigre Valles, and Daga Valles, played a significant role in flooding the Eos Chasma located to the west of Valles Marineris.

IIST faculties have also conducted research on the terrestrial analogue sites in India to understand the chemical and spectral characteristics as well as formation conditions. The terrestrial analogue studies are likely to help planetary scientists to have a better understanding of similar processes operated on the other planets.

- **Astronomy and Astrophysics**

IIST faculties along with students are involved in many areas of research in astronomy and astrophysics such as high energy astrophysics, extragalactic astronomy, star formation and evolution etc. The team is able to unify different outburst profiles of compact objects and the evolution of the accretion geometry along with the outburst The team from IIST also conducted studies on the first binary neutron star merger GW170817. This study was conducted using the Giant Meter-Wave Radio Telescope (GMRT) in Pune to detect and follow-up the radio counterpart in low frequencies.

The team in IIST is also actively involved in the researches of extragalactic astronomy. The students of IIST also conduct multi-spectral observation projects which have resulted in the detection and characterisation of diffuse halos of galaxies belonging to a wide variety of environments, adding a level of detail on the properties of non-luminous baryons in our universe.

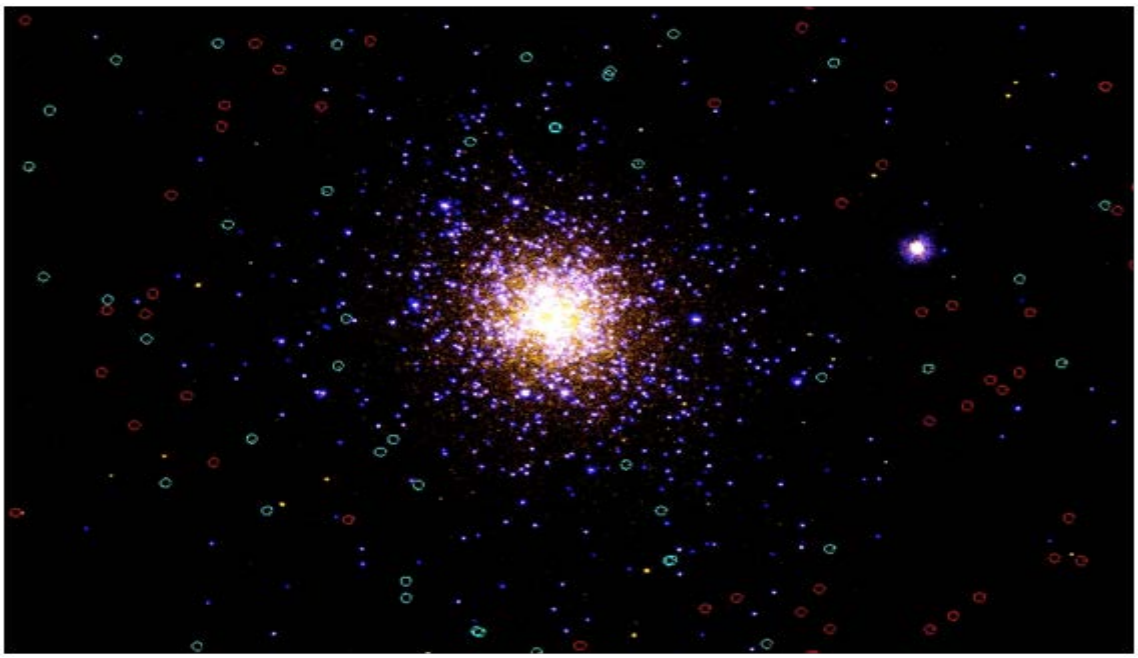

Fig 7: *UVIT-AstroSat image of the globular cluster NGC 2808, with far-ultraviolet shown in blue and near-ultraviolet in yellow. Ref: Rashi Jain, S. Vig, S. K. Ghosh, S. K. 2019, MNRAS, 485, p2877.*

The globular cluster NGC 2808 was studied in ultraviolet using the Ultraviolet Imaging Telescope (UVIT) on-board AstroSat by a team led by IIST researchers. Using different wavebands (filters), the team discovered the presence of a distinct group of red horizontal branch stars in the cluster, which sheds light on the understanding of multiple populations within the cluster. A team led by IIST researcher has discovered highly collimated HI jet from supernova remnant (SNR) G351.7. This is the first time that such a collimated HI jet is detected from such a SNR. Researchers from IIST are also involved in GLOSTAR (Global View of Star Formation in the Milky Way) survey. The initial GLOSTAR results have increased the number of HII regions in the survey part of the Milky Way by a factor of four.

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THUMBA EQUATORIAL ROCKET LAUNCHING STATION (TERLS)
THIRUVANANTHAPURAM

The Meteorology Facility (METF- WMO Code: 43371), Thumba Equatorial Rocket Launching Station (TERLS) is a prime observational, operational and advanced meteorological research facility of ISRO situated at 8° 32'N; 76° 52'E about 300 m from the Arabian Sea coast in the south peninsular India founded in 1963 by the India Meteorological Department (IMD). METF is equipped with a Class-I surface meteorological observatory, 50 m micro-meteorological tower, auto weather station, state of the art C-band polarimetric Doppler Weather Radar (C-DWR), real-time lightning monitoring, facility to launch various types of balloon sondes, support in planning, integration, launch operations and Met data analyses of sounding rockets, archival of global weather products, preparation of highly packed hand drawn streamline weather charts, daily weather forecast etc. The unique facility disseminates weather data and analyses to engineering Units within ISRO,IMD, IIST, SPL and to academic institutes for operational and research purposes.

Diagnostic study on the frequency of cyclonic and anticyclonic circulations over 6000 km^2in and around India, quantification of atmospheric NO_2 production during lightning, diurnal changes of frictional velocity and roughness length, super moon effect in atmospheric scatterers, End-Of Storm Oscillations associated to decay phase of thunderstorm, meteorological variations during a partial solar eclipse, enhancement of electric field during the subsidence conditions of an anticyclonic circulation, upper tropospheric wind steadiness factor to monitor onset of south west monsoon rains, atmospheric oscillation characteristics (0-70km)-Quasi Biennial, Annual and Semi Annual, Radar Bright Band (RBB)features of a cyclonic storm and 3D structure analysis of a water spout event are major scientific accomplishments.

A. MAJOR SCIENCE RESULTS

• Characteristics of cyclonic and anti cyclonic circulations

An exploratory study was carried out to understand the characteristics of cyclonic and anticyclonic circulations over the Indian region using the system centre lat-long data picked out from the daily hand drawn streamline analysis (2014-2019). Fig. 1(a) shows a typical day streamline chart at 850 mb. Fig. 1(b) presents the frequency distribution of cyclonic and anticyclonic circulations during the south west monsoon (SWM). Spatial distribution is depicted in Fig. 1(c & d) and corresponding frequency of occurrence for every 5°x5° grid is highlighted in Fig. 1(e & f). The pattern of cyclonic circulation closely resembles low pressure regions during SWM. The monsoon trough, equatorial trough, heat low, low pressure over the head Bay of Bengal etc. are prominent. Zonal sinusoidal distribution symmetry of monsoon trough lows is a first time result. The wide distribution in the monsoon trough suggests its north-south propagation corresponding to the active/break phases of the monsoon. The anticyclones are more frequent in the Tibetan region (Tibetan High) and

north of equatorial trough band.

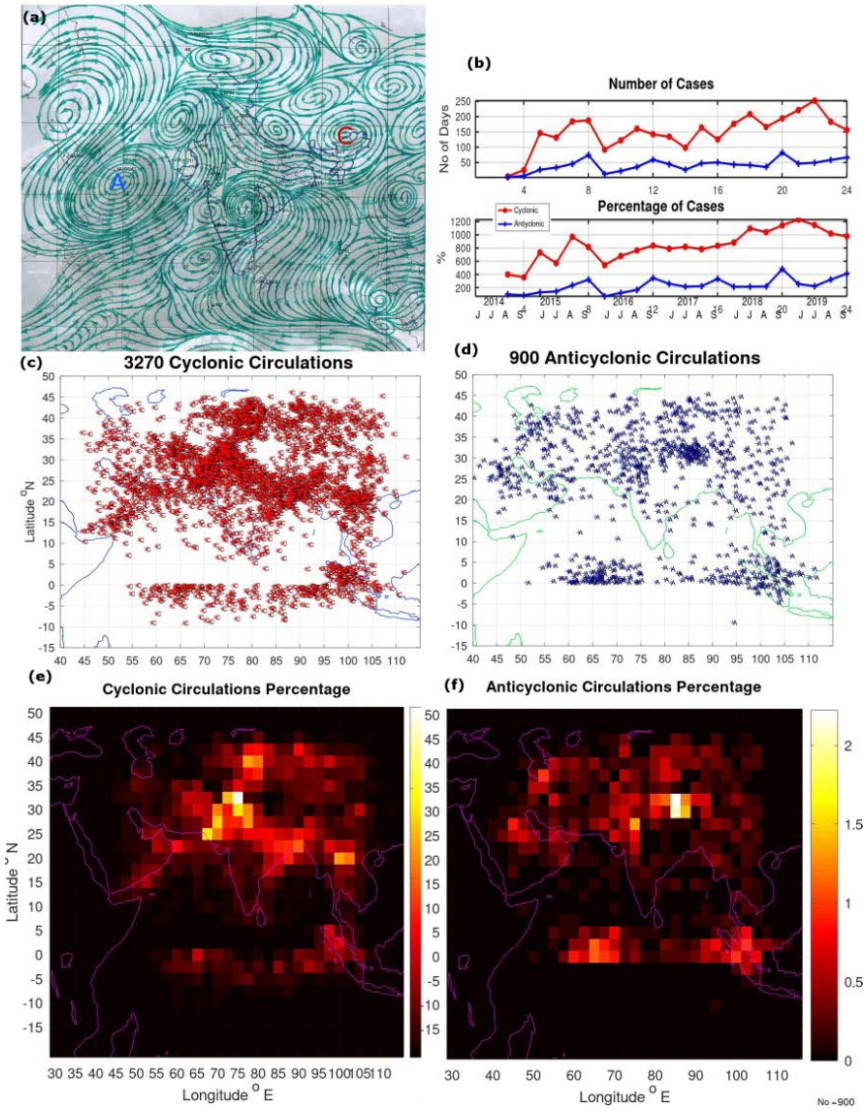

Fig.1:*(a)Streamlines at 850 hPa for 29 Jan 2019. (b) Statistics of the cases.(c&d) locations of centres of cyclonic and anticyclonic circulations (d &f) frequency distribution in percentage of cyclonic and anticyclonic circulations in a 5°x5° grid over the Indian region during the south west monsoon.*

- **Quantification of NO2 production during a lightning event**

NO_2 production during lightning activity is studied in comparison with atmospheric electric field on 28 April 2020. During the event at 16:00 IST maximum NO_2 value of 34 µg/m^3 and electric field of 10000 V/m values are observed (Fig. 2)

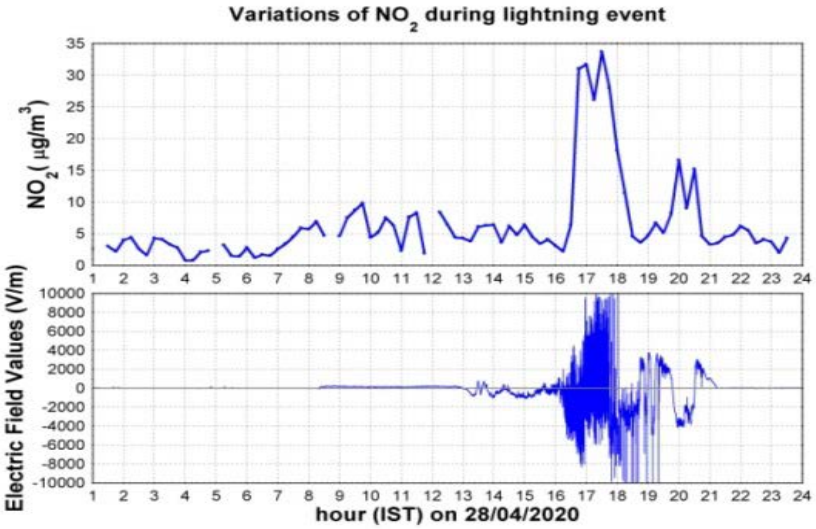

Fig.2: *Variation of (a) NO_2 and (b) Electric Field values during the course of a lightning event on 28 April 2020:1600 IST.*

- **Mean diurnal variations of frictional velocity (U_*) and roughness length (Z_0)**

Fig. 3 represents diurnal variations in U_* and Z_0 derived from wind speed sensors at the 50 m micrometeorological tower (log wind profile method) and from a sonic anemometer at 3.3 m (eddy correlation method) separated by 200m of varying vegetation features. Variability in U_* and Z_0 may be attributed to roughness elements, wind stress, wind direction, heat flux and momentum flux.

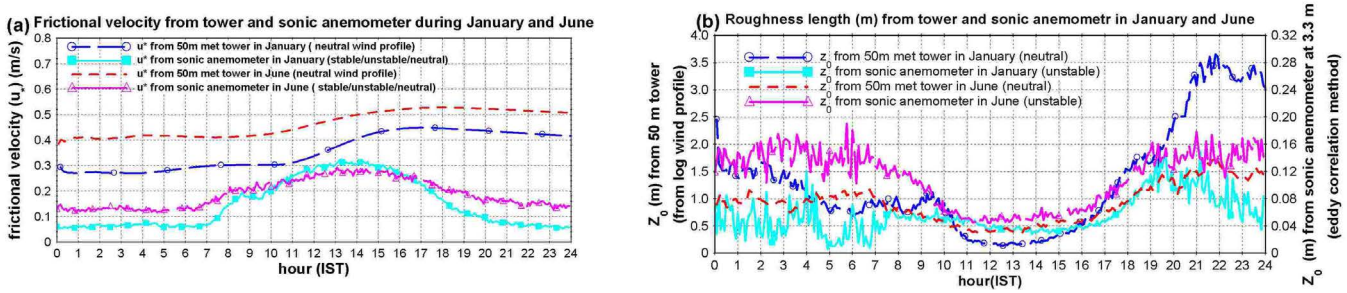

Fig.3: *Mean diurnal variation of frictional velocity and roughness length.*

- **Super moon effect in atmosphere – first time observations using DWR**

Fig. 4 represents the differential reflectivity and its rate of change on the super moon day 31 January, 2018. Remarkable change in ZDR as a sudden decrease followed by an increase is found during the totality phase (18:21 IST to 19:37 IST) on this clear day which suggests atmospheric pressure oscillations due to gravitational tidal forcing where the scatterers undergo contraction and elongation.

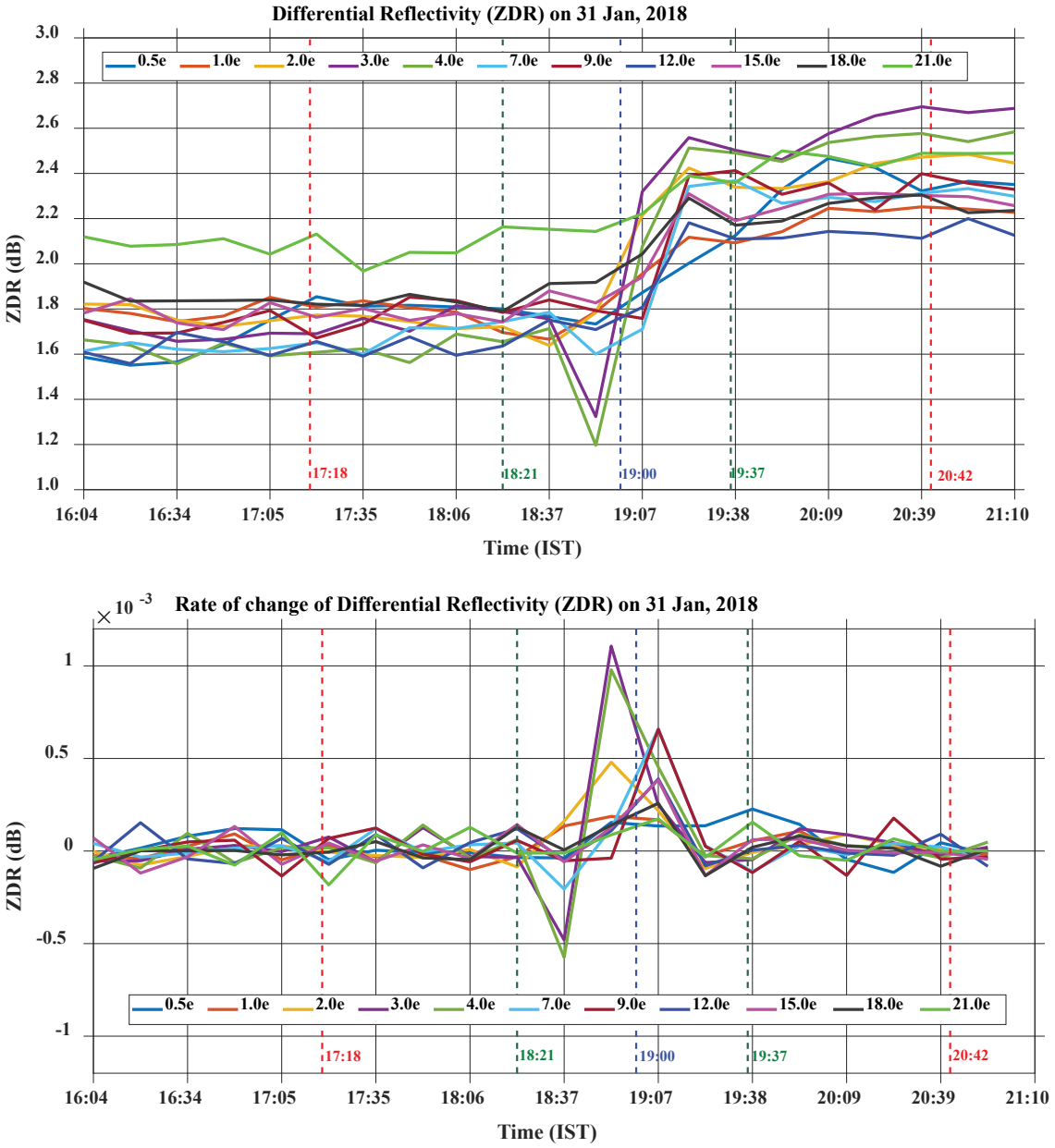

Fig. 4: *Differential reflectivity and its rate of change on 31 January, 2018. Greatest phase (blue), time period between (green) &duration (red) vertical lines.*

- **Identification of End of Storm Oscillation (EOSO)**

Presence of EOSO in e-field can be considered as the dissipation phase of the thunderstorm (Fig. 5). There were positive/negative phases during EOSO and noticed more than one cycle in each EOSO episode. It has been identified that the dissipation phase lasts more than 2 hours for the observed thunderstorm. Variations in Z_{DR} with EOSO are also studied.

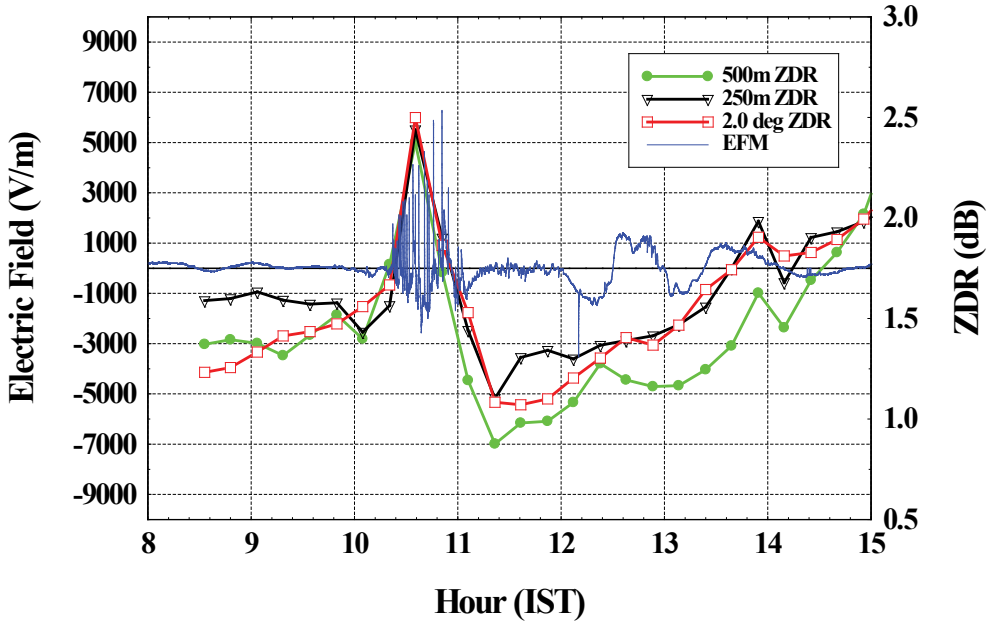

Fig. 5: *Electric field and Z_{DR} during thunderstorm show EOSO characteristics*

- **Observations of atmospheric changes during a partial solar eclipse**

Campaign mode observations were conducted during the Annular Solar Eclipse on 26 December 2019. Eclipse was partial over Thiruvananthapuram with 87.57% coverage of the Sun with magnitude of 0.9122. Eclipse was from 08:07:02 IST maximized at 09:30:18 IST and ended at 11:11:59 IST. Partial eclipse begins during the land breeze regime (~45° wind direction). Veering of wind direction is noticed until the maximum phase of eclipse (Figure not shown). Maximum veered direction is ~355°. After the maximum phase of eclipse, with a lag of approximately 20 min, wind direction suddenly changes to ~ 40° (backing of wind). A delayed onset of sea breeze is notice around 10:40 IST compared to the Sea breeze onset at 0840 IST on the pre-eclipse day. Surface isobaric analysis showed no prominent weather systems over the region on the eclipse day. The surface temperature decreased by 1.0°C with relative humidity increase of 8% was seen at the greatest phase. The solar radiation value reduced to 35 from 100 Wm^{-2} within 45 minutes with remarkable decrease in vertical heat fluxover Thiruvananthapuram. While, over Coimbatore where eclipse was maximum and perfectly annular, reduction in insolation was from 70 to nearly 10 Wm^{-2}. Decrease of Monin Obukhov Length due to subdued turbulence and decrease of electric field due to ionospheric changes/ unavailability of salt aerosols are notable features. RH 200 rocket chaff wind reveals marked difference with next day and meridional wind profile on the eclipse day suggests a vertically propagating wave of wavelength 4-5 km.

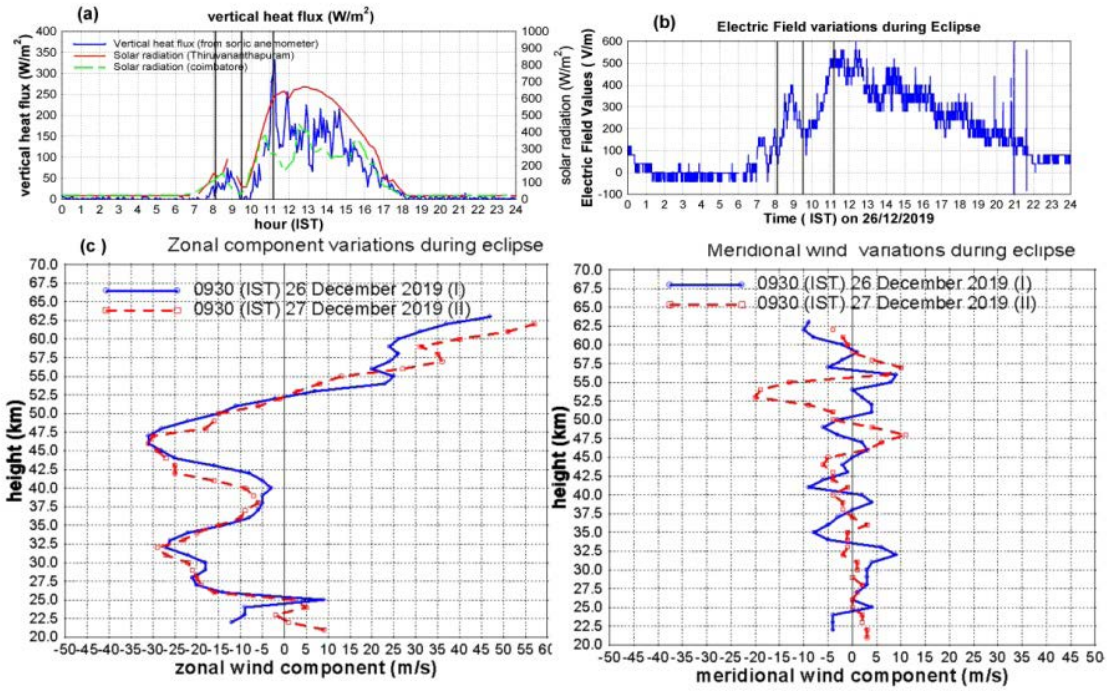

Fig. 6: *(a) Diurnal variation of solar radiation, vertical heat flux. (b) electric field variations (c)vertical profile of zonal and meridional wind components on the day of eclipse and next day.*

- **Electric field variations during an anticyclone**

Even though in subsidence day time conditions due to anticyclone, high atmospheric electric field values of about 600 V/m(on par with cloudy weather) caused by charge separation between sea salt aerosol and stagnant dust (less temporal variability in PM10 with eddy size 300m and low TKE) was investigated in a case study (Fig. 7)

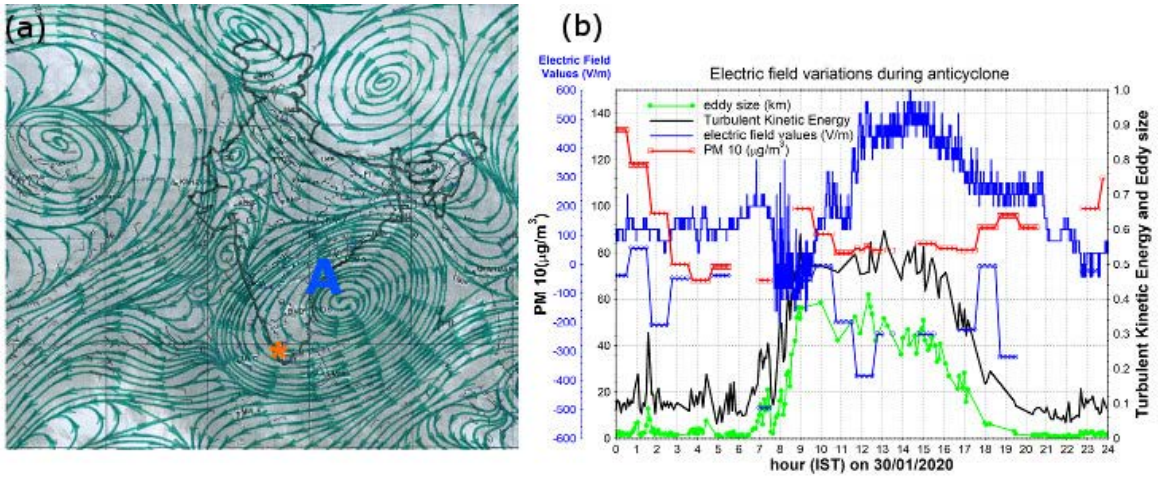

Fig. 7: *(a) anticyclone at 850 hPa for 30 January 2020. (b) diurnal variations of eddy size, Turbulent Kinetic Energy (TKE), electric field and PM10 concentration.*

- **Wind Steadiness Factor (WSF) and onset of monsoon**

Upper tropospheric WSF consistently above 90 % for about 7-10 days is a precursor for monsoonal rains. The Fig.8 shows the daily variations of WSF in the years 2018, 2019, 2020. Monsoon onset dates declared by IMD are provided in Fig.

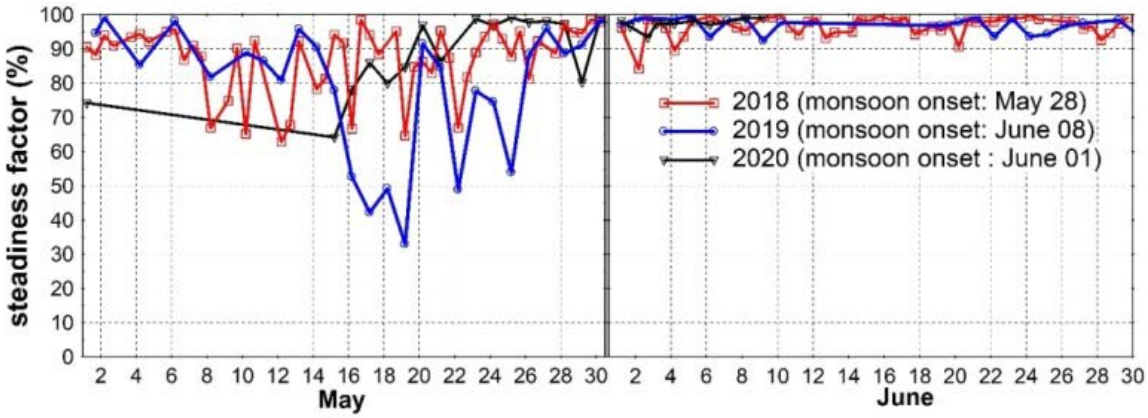

Fig. 8: *Wind steadiness factor from 01 May to 30 June for 2018, 2019 and 2020*

- **Winds study from RH 200 rocket launches**

The horizontal wind vector for all the rocket launches are represented in the Fig.9(a) and zonal components in Fig.9(b). Signatures of stratospheric quasi-biennial oscillations, mesospheric semi-annual oscillations are evident from the figure. Westerly regime is more pronounced in the higher levels while easterly regime dominates in lower heights.

- **Radar Bright Band (RBB) characteristics**

RBB occurs during thunderstorm, active monsoon clouds and cyclonic storms at an altitude of ~0° C isotherm where ice and water co-exists provides a large backscatter area for radar signals has attention in aviation and aerospace meteorology. Fig.10 (a) shows the map of radar reflectivity for different elevation angles during RBB. 3D structure of a water spout on 26 November 2017 is shown in Fig.10 (b).

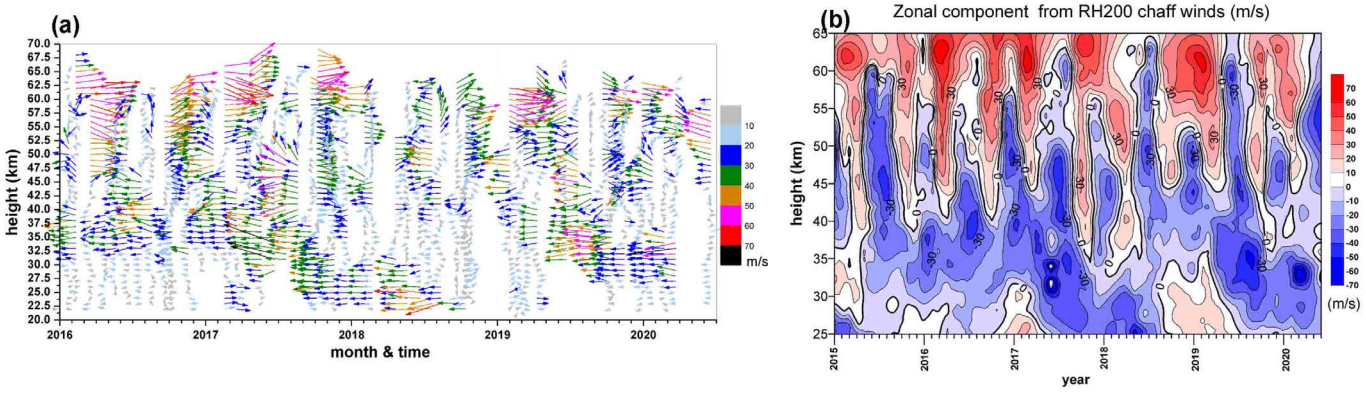

Fig. 9: *(a) Vertical profile of wind vectors and (b) zonalwind component of RH-200 winds.*

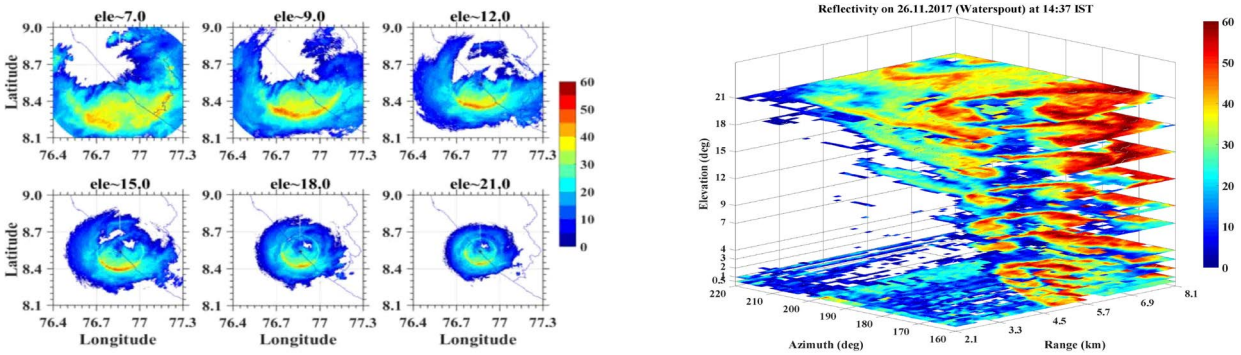

Fig. 10: *(a) Spatial plot of Radar reflectivity on 30.11.2017 at 08:49 IST for different elevation angles for RBB. (b) 3D structure of a water spout on 26 November 2017:1437 IST.*

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SEMI-CONDUCTOR LABORATORY

Chandigardh

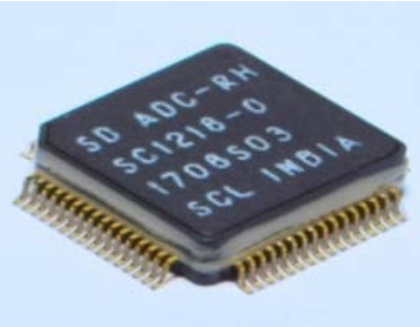
Semiconductor Laboratory (SCL) is engaged in providing end-to-end solutions for Development of Application Specific Integrated Circuits (ASICs), Opto-electronics Devices and Micro Electro Mechanical System (MEMS) Devices encompassing Design, Fabrication, Assembly, Packaging, Testing and Reliability Assurance. SCL has 180nm, CMOS, 8" Wafer Fabrication Line as per international standards and has a 6" Wafer Fabrication Line with CMOS/MEMS process capability. The efforts at SCL are directed towards creating a strong microelectronics base with activities focused on realization of critical and high reliability device requirements for Space and to meet other strategic requirements of India. Enhancements of Baseline 180nm CMOS Process have been undertaken in order to cater to wider spectrum of devices and there is continual efforts to scale down the technology to advanced node i.e. 65/45 nm, 12 Wafer Fabrication facility. SCL is also engaged in Fabrication of Hi-Rel Boards for DOS/ISRO Centres/Units, Assembly of Radio Sonde Systems for Atmospheric Studies and indigenization of Electronic Sub Systems for other applications.

A. Major Developments / Realizations of Devices / Processes

SCL Design team has successfully fabed out 15 Multi Project Wafers (MPW) Lots consisting of 1156 (One Thousand One Hundred & Fifty-Six) Wafers and 166 (One Hundred & Sixty-Six) Designs of New Products (ASICs/IPs/Test Chips) during this period, majorly for use in Space Application. SCL has developed technology for Radiation Hardness by Design (RHBD). Devices, for space applications.

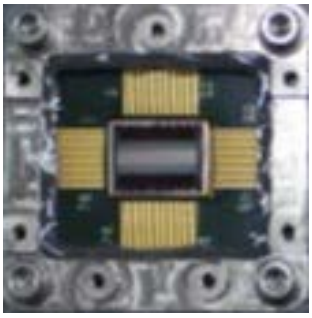
Vikram Processor 1601, one of the key components for Launch Vehicle has been successfully realised, has been flown in Navigation Interface Module (NIM – 400) in both Prime & Redundant Chains, On-board PSLV- C47 and performed well. SCL's Rad Hard (RH) 24-bit Sigma Delta Analog to Digital Converter (ADC) has been flown in Digital Mini Magnetometer (DMM) of CARTOSAT-3 and its performance is as per design. Further, SCL make Vikram Processor 1601 has also been flown in Prime Chain of Navigation, Guidance & Control Package On-board PSLV- C48 also and has performed flawlessly.

Vikram Processor 1601



RADHARD 24-bit Sigma Delta ADC

Hyper-spectral Image Sensor (HysIS): A Flight Model (FM) Optical Imaging Detector fabricated in SCL's Wafer Fab and assembled & packaged on a Chip-On-Board (COB) Imaging Module has flown on HysIS Satellite on-board PSLV-C43.

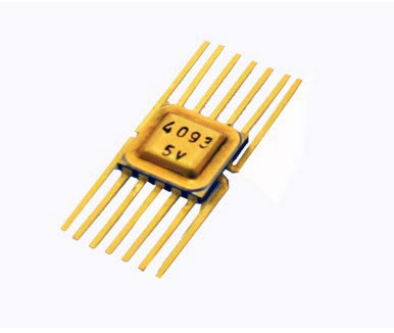


Hyper-spectral Image Sensor (HysIS) Detector

Other Devices fabricated and delivered to ISRO/DOS Centres/Units and Other Organizations are as below:

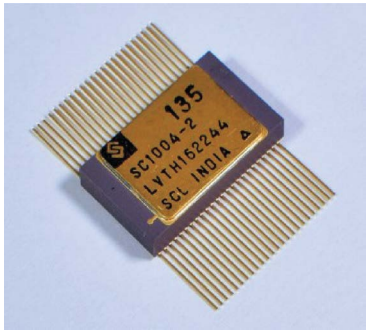
- **Flight Model Devices:**

FM Hex Schmitt Trigger Inverter

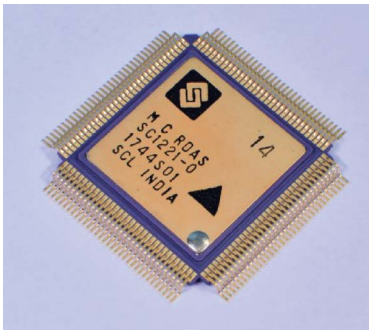


FM Two Input NAND Gate

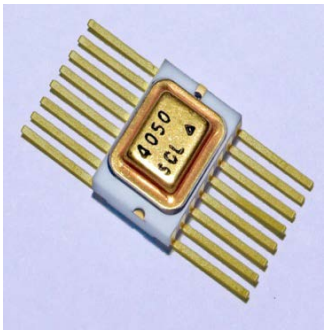
FM On Board Controller 2.3



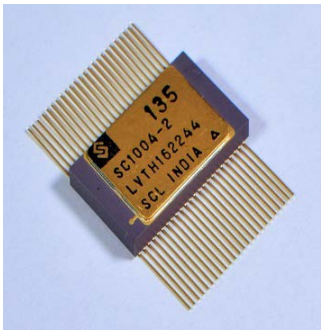
FM 16-bit Buffer



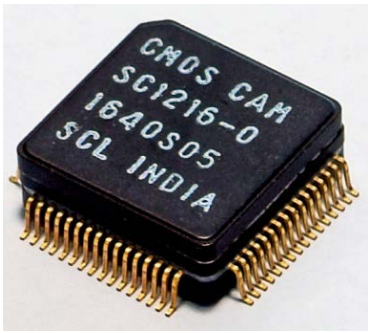
FM Multi Core Re-Configurable Data Acquisition System



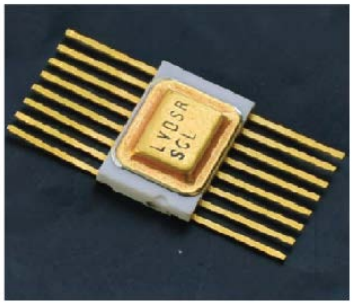
FM Hex Buffer

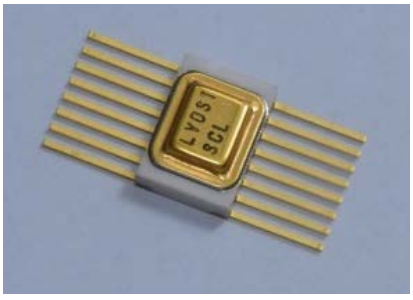


FM 16-bit Buffer

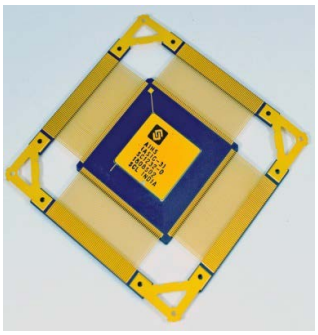


FM CMOS Camera Conf. ASIC

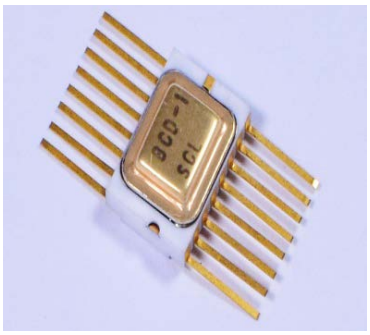




FM Low Voltage Differential Signalling Receiver & Transmitter



FM Actuator Interface for Heating Switch



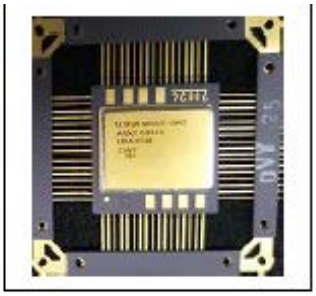
FM BCD1 Clock Driver

FM Digital Binary Phase Shift Keying

- **Memories:**

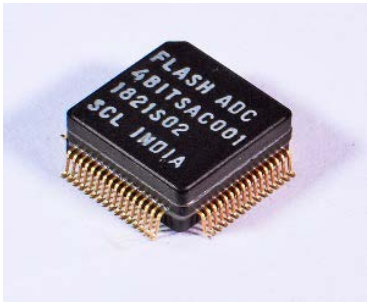
2MB SRAM

32KB SRAM



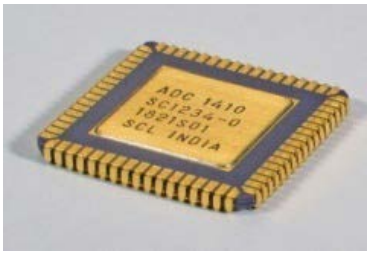
16 MB SRAM

- **Analog to Digital Converters**

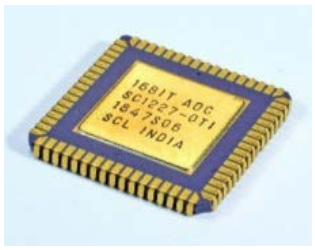


4-bit Flash ADC

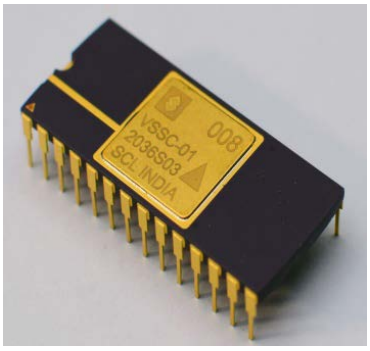
12-bit ADC



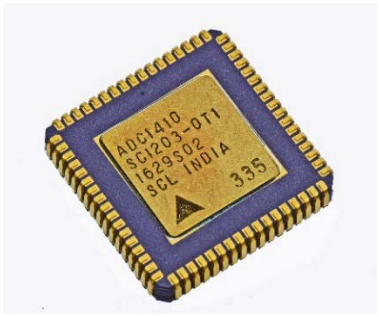
14-bit ADC



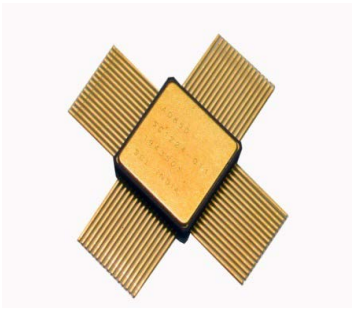
16-bit ADC



Successive Accumulation Register (SAR) ADC



14-bit Pipeline ADC

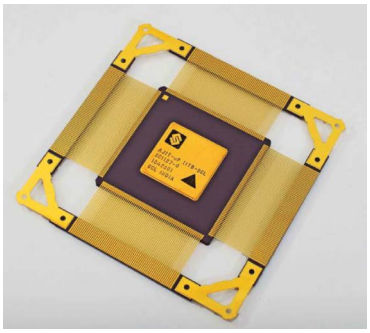


8-bit 250 MSPS ADC

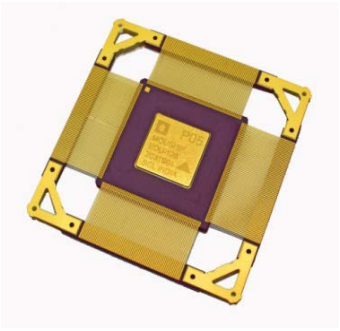
- **Microprocessors:**

Vikram 32 Processor

Shakti Processor for IIT Madras



Ajit Processor for IIT Bombay

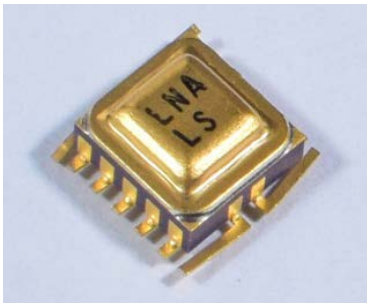


Shakti E Class Processor for IIT Madras

- **Amplifiers:**

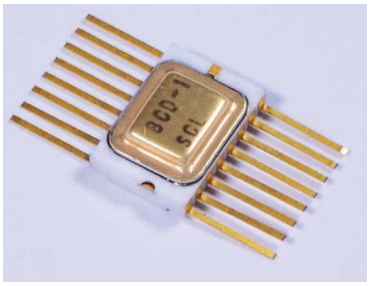
16 Channel Charge Sensitive Amplifier

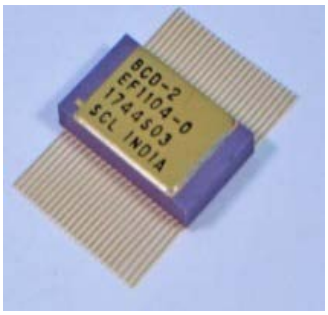
C to V Amplifier

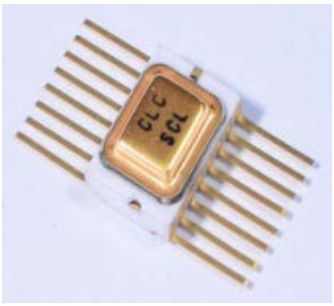


Low Noise Amplifier

- **Clock Drivers:**

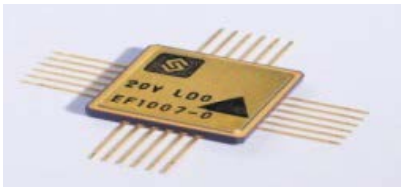


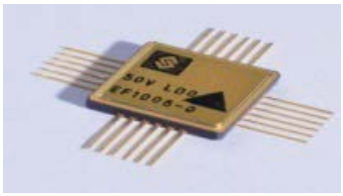




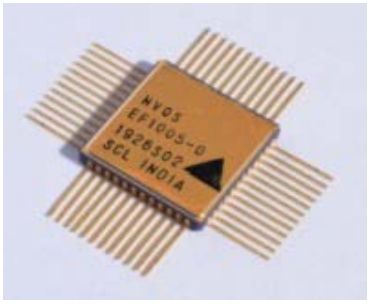
Different Variants of Clock Drivers

- **Voltage Regulators:**

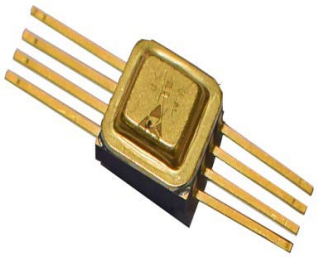




20V & 50 V Low Dropout Voltage Regulators (LDOs)



High Voltage Solid State Switch



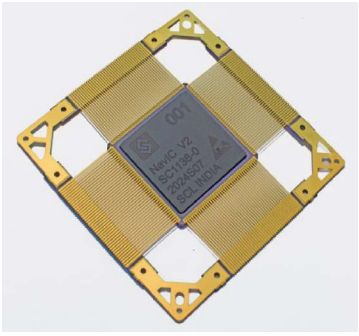
Voltage Supervisory Circuit

- **Opto-electronics Devices:**

Silicon Photomultiplier Sensors

Frame Transfer CCD for OCM 3

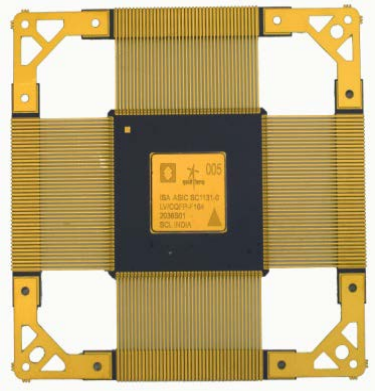
- **Other ASICs:**



Digital ASIC for NavIC (Indian Regional Navigation Satellite System – IRNSS)

CCD Signal Processor ASIC

Pulse Width Modulation Controller ASIC



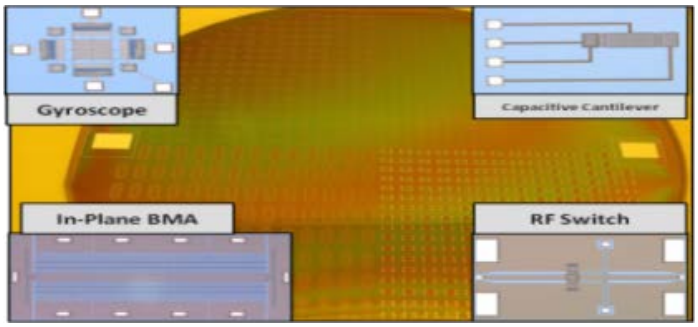
Inertial Sensor Acquisition ASIC

- **Micro Electro Mechanical Systems (MEMS)**

SCL 6” foundry is dedicated for the development of various MEMS/NEMS devices and Silicon based Photodetectors. It provides both customized processes as well as standard MEMS process solutions to the customers.

Fab-out of First Integration Lot of SOI-MMPW & PIEZO-MMPW each on 20th August 2018

In 2018, maiden lot of standardized MEMS process (MEMS Multi Project Wafer, MMPW) has been successfully demonstrated. It encompasses three standard MEMS processes namely SOI-MMPW, PIEZO-MMPW and POLY-MMPW. Users can select these standard processes and design the MEMS products.



Poly MMPW Wafer

0-5 and 0-10 bar oil filled pressure transducers have been designed, fabricated, packaged and qualified. 0-1 bar Absolute Pressure Sensor designed, developed, packaged and delivered to VSSC.

MEMS Acoustic Sensor with AlN as piezoelectric layer

Absolute Pressure Sensor 0-1 Bar & 0-30 bar

6 to 12 bar Pressure Sensor

Indigenous MEMS Acoustic Sensor (IMAS) is developed jointly with VSSC for launch vehicle applications. The performance of the sensor in SS3-ST-02 static test at SDSC-SHAR is comparable with imported Endevco sensor.

Metal Oxide Based gas sensors have been developed and demonstrated for NO_2, N_2H_4, O_2 and H_2 for ground applications at SDSC-SHAR.

ISMA (IISU SCL MEMS Accelerometer) to measure bending mode acceleration of launch vehicle was successfully flight tested on PSLV C50. Its MEMS sensing element was designed, fabricated and packaged as multi-chip-module along with readout IC at SCL. This is a joint development with IISU team for micro-g class open loop sensor development.

micro-g class MEMS Accelerometer with close loop Readout Integrated Circuit (ROIC)

The current activities involve the development of new process technologies for device manufacturing in line with set Road Map for upgradation of Semi-Conductor Fab-Line. These include Yield Enhancement of existing processes, setting up the new Technology Development facilities i.e. GaN on Silicon for high power devices and SiGe-Bi-CMOS Technology for high speed devices.

The 180 nm, 8inch CMOS facility is supplemented with 0.8 um, 6-inch Wafer Fabrication Facility for fabrication of MEMS devices and sensor i.e Pressure, Temperature, Humidity, Gas, Piezo resistive Shock Sensors, Baro-Altimeter, Gyroscopes, Uncooled Micro Bolometer, Micro Propulsion – Electro Spray Thrusters required for different Launch Vehicles and for Gaganyaan Project to list a few.

Enhancement of existing technologies in the area of Electro-Optical Devices is focused to scale-up device performance in different wavelength to cater wider spectrum of devices required for Satellite, Launch Vehicles and other Strategic needs. Development of QDSC (Quantum Dot Solar Cell) Technology is in progress for high efficiency of Solar Cells for Space applications.

SCL is working towards the setting up of advanced Screening, Qualification and Reliability Test laboratory for FM Devices & Sensors to be used in ISRO/DOS Missions. SCL is also looking forward to scaling down the existing 180 nm Fab to 65/45 nm, 12-inch Wafer Semi-Conductor Fabrication Facility.

It is not out of context to mention that by utilizing the existing as well as the above mentioned advanced technologies, supplemented with Indigenization of Spares / Consumables, will help the Electronic System and Design Manufacturing (ESDM) complimenting the" India Digital Program" and transforming Indian Economy to "Knowledge Based Economy".

Contact detai: Group Head-Project Planning Group, Email: at@scl.gov.in

INDIAN INSTITUTE OF REMOTE SENSING
Dehradun

The Indian Institute of Remote Sensing (IIRS) is a constituent Unit of Indian Space Research Organisation (ISRO), Department of Space, Government of India. Since its establishment in 1966, IIRS is a key player in the Southeast Asia for training and capacity building in the field of remote sensing and its applications through training and education programmes at postgraduate level. The capacity building programmes of the Institute are designed to meet the requirements of professionals at multiple levels from fresh graduates to decision makers including academia. It is one of the most sought after institutes for conducting customized training courses for the officers from Central and State Government Ministries and stakeholder departments for the effective utilization of Earth Observation (EO) data and geospatial technology. IIRS is identified as the nodal centre for conducting the short-term courses to international participants under the Indian Technical and Economic Cooperation (ITEC) programme of the Ministry of External Affairs, Government of India. Apart from on-campus courses, online courses are also offered in two modes: (i) interactive live courses, and (ii) e-learning (MOOC) courses in Remote Sensing and Geo-information Science. A total of 631 and 749 participants have joined various regular and tailor-made courses in the calendar year 2018 and 2019.

The Institute has a strong, multi-disciplinary and solution-oriented research agenda that focuses on developing improved methods/ techniques for processing, visualization and dissemination of EO data & Geo-information for various societal applications and better understanding of Earth's system processes. Some of these studies are highlighted in this document.

IIRS hosts headquarters of the Centre for Space Science and Technology Education in Asia and the Pacific (CSSTEAP), affiliated to the United Nations, and provides support in conducting the Remote Sensing and GIS training and education programmes.

A. MAJOR FACILITIES/ INSTRUMENTATION

- **GNSS and Seismic stations network for geodynamics studies:** Established 11 permanent GNSS stations, 02 seismic stations and 01 Earthquake early warning system in different parts of the Western Himalaya.
- **GNSS receivers:** For coordinate and survey data collection and precise positioning and orientation.
- **Snow Pack Analyser & Snow Depth Sensors:** Installed 01 snowpack analyser and 04 snow depth sensors in the Western Himalaya for measurement of snow properties.
- **Skyradiometer**: Established at Dehradun to provide Aerosol Optical Depth, Aerosol Angstrom exponent, Asymmetric parameter, direct and diffuse solar radiation in 7 narrow bands within 315-2010 nm wavelength range.

- **Trace Gas Laboratory:** Established at Dehradun for continuously monitoring air pollutants like ozone, CO and NOx.
- **Ceilometer:** Established at Dehradun by Physical research Laboratory (PRL), Ahmedabad for measurement of cloud base height and boundary layer height based on backscatter LiDAR signal in 900-910 nm wavelength range.
- **Spectroradiometer:** Operating in 350-2500 nm spectral region for spectral measurements.
- **Terrestrial Laser Scanner:** For acquisition of ultra-high-density 3D point cloud in the visible and near infrared wavelengths.
- **Underwater Spectroradiometer:** For measuring spectral response of water (surface and below surface) in 400–2500 nm wavelength range.
- **Echo-sounder with Autonomous Floating Device:** For hydrographic/ bathymetric studies of inland water bodies.
- **IIRS Learning Management System:** Developed for online training courses.

B. MAJOR RESEARCH

- **Effect on Air Quality over India due to COVID-19 induced lockdown**

To contain the wide spread of corona virus (COVID-19), from March 25, 2020 Government of India announced lockdown for its 1.3 billion people for three weeks. Subsequently, keeping in view of the spread of the virus, government extended the lock down to further 19 days from April 15 till 3 May, 2020. From April 15-May 3, 2020 except agricultural and few essential economic activities everything was under lockdown which extended in phases till 31 May 2020 with different levels of intervention, including national and international road, rail and air travel, complete or partial lockdown of people's movement, industrial and economic activity, markets and social activities. The study focusses to assess changes in air quality by analyzing spatial distribution and variation in Aerosol Optical Depth (AOD), tropospheric column nitrogen dioxide (NO_2) during COVID-19 induced lockdown over India. Also, quantification of reduction in surface level NOx over different Indian cities and effect of NOx exposure on COVID-19 related mortality was studied.

Data used

Daily level-2 MODIS Aqua and Terra AOD data at 0.1deg resolution over Indian region was used from 1 January to 03 May for the years 2017-2020. In order to understand the trend and possible changes in air quality, we used two time periods, one from 1January-24March as pre-lockdown (PLD) and 25March-15May as during lockdown (DLD). We examined daily changes in AOD from 1January-15May during 2017-2020 to investigate the effect of lockdown on their daily concentration. In addition, MODIS active fire product at 1 km resolution both Terra and Aqua, over Indian region were used for assessing the fire events over India during 1March-31May during 2017-2020. Sentinel-5P TROPOMI level-3 gridded at 7x7 km product & OMI level-3 gridded

product at 0.25x0.25 deg. was used for tropospheric column NO_2 during 2018-2020 for the pre and during lockdown phase.

Salient Results

The major findings of the study are summarized as:

- MODIS observations show an average reduction of 20-37% in aerosol loading during lockdown period (compared to 2017-19 period) across India particularly over North India, Indo Gangetic Plain (IGP) and peninsular India (Fig.1). A consistent and drastic reduction of Aerosol loading over northern India is observed from March 25, 2020 onwards (DLD) wherein the AOD values are observed to be as low as 0.18 which is lowest as compared to the 3 years average AOD values (2017-19) over the region (Fig.2). MODIS fire hotspots reveals a drastic reduction of 65–85% in seasonal fire events over northern India and IGP during April–May 2020, compared to previous years, in conjunction with reduced anthropogenic emissions which is responsible for reduced anthropogenic emission of aerosols.
- The ground level measurement of air pollutants (PM_{10}, $PM_{2.5}$, NO_2 and SO_2) collected by CPCB across selected Indian cities shows a reduction of these pollutants of around 30-45% in as compared to pre-lockdown period.
- A detailed analysis of the NO_2 concentration using TROPOMI before and during lockdown indicates a 30–50% reduction in the levels of NO_2 across the country.
- The difference between trop. column NO_2 distribution during 2020 lockdown period with same period of 2017-2019 using OMI shows that conc. decreased by more than 1 x 10^{15} molecules/cm^2 over the Indo-Gangetic Belt, eastern and southern India. This is due to operation of few thermal power plants (capacity more than 2000MW) as the overall energy consumption had fallen by 30% (Fig.3).
- The effect of lockdown is clearly seen from CPCB surface NOx which shows abrupt reduction after 25March, 2020 over New Delhi, Mumbai, Kolkata and Bangalore. Daily peak NOx value of 60-80 ppbv over Mumbai and Bangalore and 100-250 ppbv over Delhi and Kolkatta is observed after 25th March over these megacities (Fig.4).
- The relationship of long term averaged TROPOMI NO_2 (March 2018-December 2019) with the rate of mortality in India due to COVID-19 pandemic (as on 18 May 2020) revealed that higher mortality were reported in areas which had a long term exposure to NO_2. Nearly, 53% of COVID-19 positive cases and 61% of fatality cases (1859 deaths out of total 3039 deaths in India) were observed in the eight major cities of India (as on May 18,2020) coinciding with locations having high long-term NO_2 exposure (Fig. 5). It corroborates the fact that long-term exposure to NO_2 has weakened the immune system and had profound effect on inflammation of the lungs.

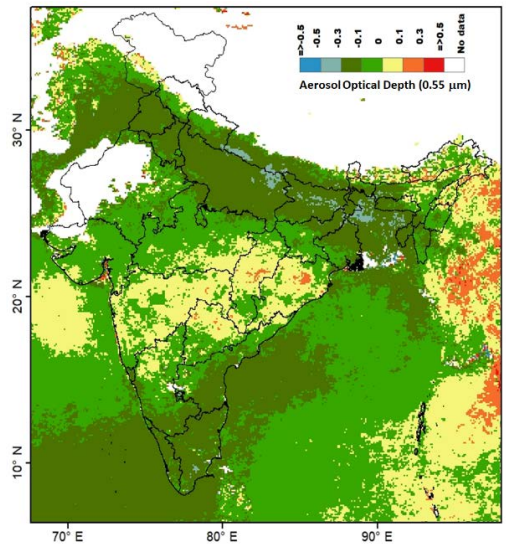


Fig. 1: *Aerosol Optical Depth Anomaly in 2020 (25Mar-3May) with average for 2017-19 same time period*

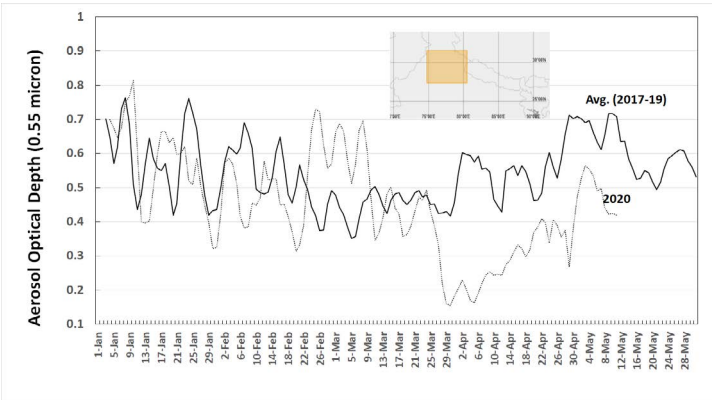
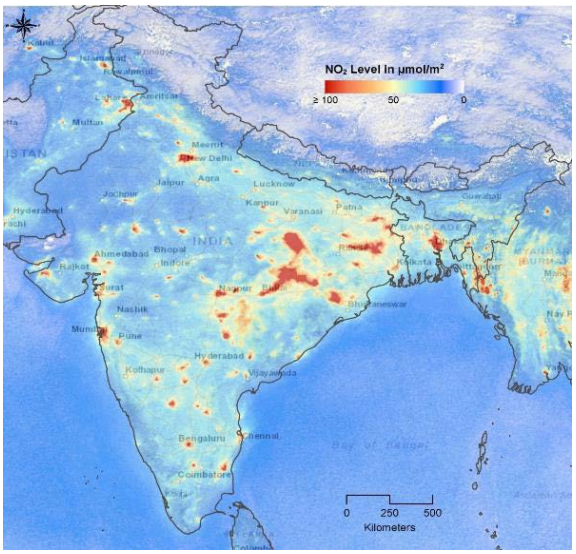
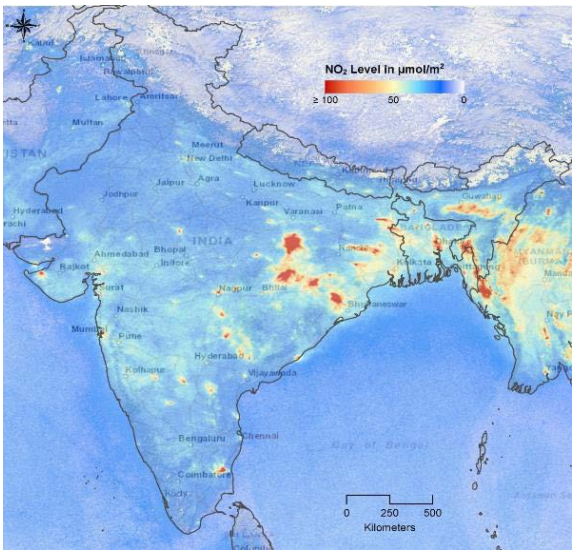


Fig. 2: *Time series analysis over northern India during 2020 and its comparison with period of 2017-2019.*



(a)



(b)

Fig. 3: *NO_2 level during lockdown period from March 24 to April 7, 2020, for (a) 2019, (b) 2020*

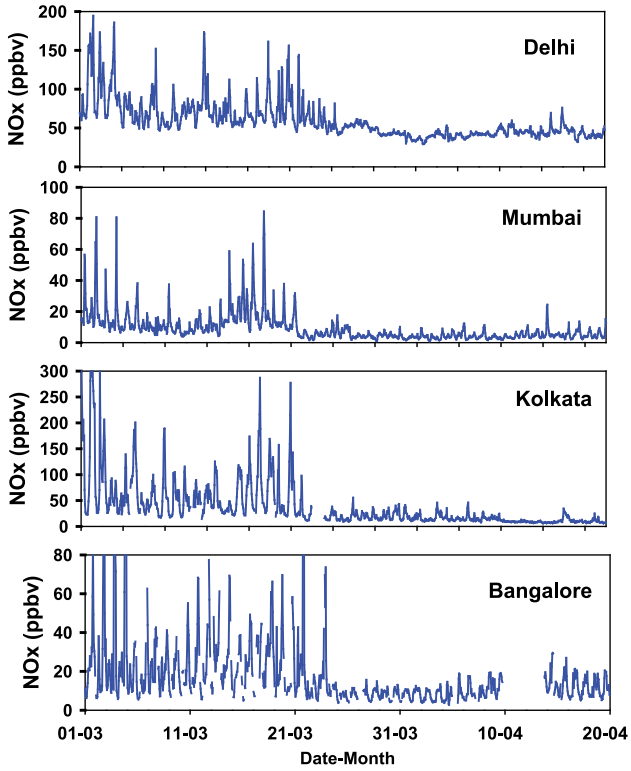


Fig. 4. Time series variation of hourly average NOx over five major Indian cities before and during lockdown phase (25March-15May, 2020)

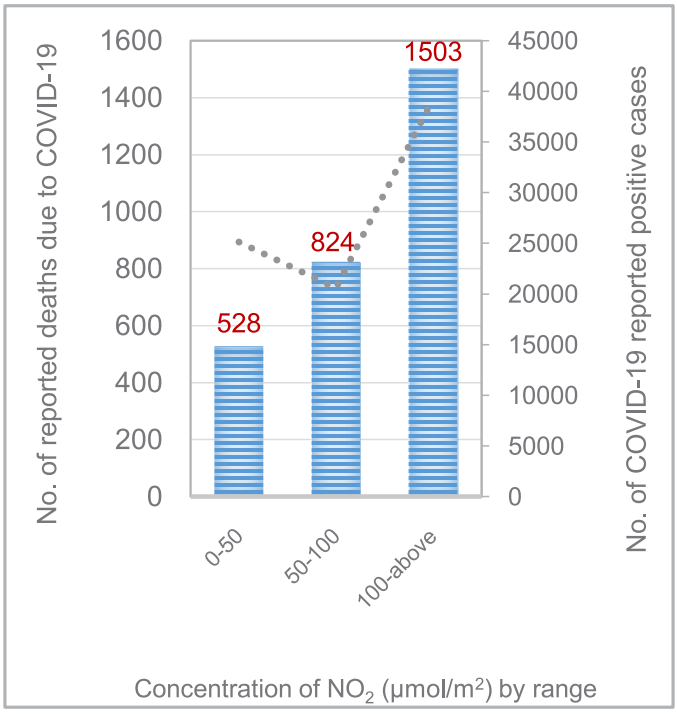


Fig. 5. *Concentration of NO_2, reported cases and deaths due to COVID-19 as on 18 May, 2020*

- **Remote Sensing of Earth's Resources and Environment**

➢ Active deformation across the Himalayan Frontal Thrust

In this study, non-invasive geophysical techniques were employed across the Himalayan Frontal Thrust (HFT) at Singhauli in the north-western frontal Himalaya to understand shallow subsurface geological structures and their nature in the context of active tectonics. The combination of high-resolution Ground Penetrating Radar (GPR), Electrical Resistivity Tomography (ERT) and Multi-channel Analysis of Surface Waves (MASW) techniques were found to be beneficial in gaining high-resolution images of shallow subsurface geological structures. A strong correlation has been established between the field-based geological observations carried out earlier in this area through a trench excavation survey with the present work using geophysical techniques. The integrated approach is found to be highly beneficial in those areas where contrasting lithological units exist in terms of their physical properties. This study argues for judicious use of the ERT, GPR and MASW techniques to delineate shallow subsurface geology across various active faults in the Himalayan terrain to comprehend the active deformation related to large magnitude palaeo-earthquakes and earthquake hazard assessment.

➢ Water quality studies in Chilika Lake

The water quality of Chilika Lake (India) with regard to turbidity concentration has been studied using airborne hyperspectral remote sensing data (AVIRIS-NG). A spectral library, specific to Chilika Lake water quality parameters, has been generated using sophisticated instruments like field spectro-radiometer, turbidity meter and hand-held GPS. The most widely used Spectral Angle Mapper similarity analysis was adapted**.** A very high similarity between the image spectrum and field spectrum was found. As, the field spectra were classified into 7 classes of turbidity concentration as < 5, 5-10, 10-15, 15-25, 25-45, 45-100 and >100 NTU, SAM classified image resulted in these 7 classes of turbidity in the selected region of the lake.

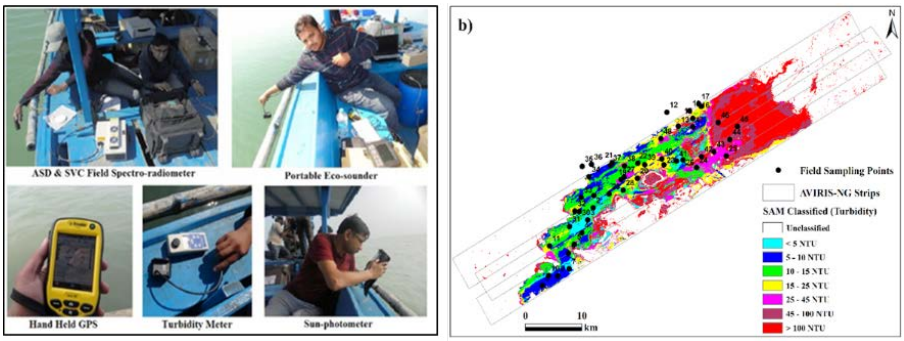


Fig 6: *Field measurements and classified turbidity Map, Chilika Lake (India)*

➢ Estimation change in snow water equivalent in the North-West Himalaya

This study has utilized the daily Ku-band high-resolution Level-4 backscatter product from the ISRO's first dedicated Scatsat-1 satellite to derive the change in the *snow water equivalent* (SWE)

for the North-Western Himalayan (NWH) region. The SWE is the most important snowpack parameter for hydrology. In this regard, the microwave radars, such as the Scatsat-1, the dry snow for the horizontal polarization at 50° incidence angle shows that backscatter agrees well with the Rayleigh-scattering. This method was used for estimation of change in SWE for 2016-2020 winter seasons at every 15 days interval.

➢ Glacier and glacial lake interactions in the Central Himalaya

This study investigated the variations in glaciers and glacial lakes in the central Himalayan region during 1994 to 2017. The analysis of satellite images of 1994, 2015 and 2017 reveals that the numbers as well as the area of glacial lakes in the region are continuously increasing under a glacier mass wasting scenario. The rate of expansion is more in the larger lakes as compared to the smaller ones. A strong relationship between the proglacial lakes and the mother glaciers is also observed.

➢ CO_2 exchange characteristics of Indian forests

To assess the carbon sequestration potential of natural and planted forests, eddy covariance (EC) towers were set-up under the National Carbon Project (NCP) of ISRO-Geosphere Biosphere Programme (IGBP) at two sites in the Uttarakhand State of India: (1) Barkot Flux Site (BFS) located in the mature natural forests [moist deciduous forest dominated by sal (Shorea robusta)], and (2) Haldwani Flux Site (HFS) in the planted forests (comprising associated species of Shorea robusta). The study reveals that both the mature forests (-719.43 gC m^{-2} $year^{-1}$) and young plantation (-467.49 gC m^{-2} $year^{-1}$) are absorbing significant amount of atmospheric CO_2. Maximum uptake of atmospheric CO_2 is found to occur during the post-monsoon season. Among the environmental factors, soil moisture exercises maximum control on the productivity. The integrated analysis of EC data and Biome-Biogeochemical Cycle (Biome-BGC) model showed that the sal forests of Uttarakhand act as a net sink of carbon.

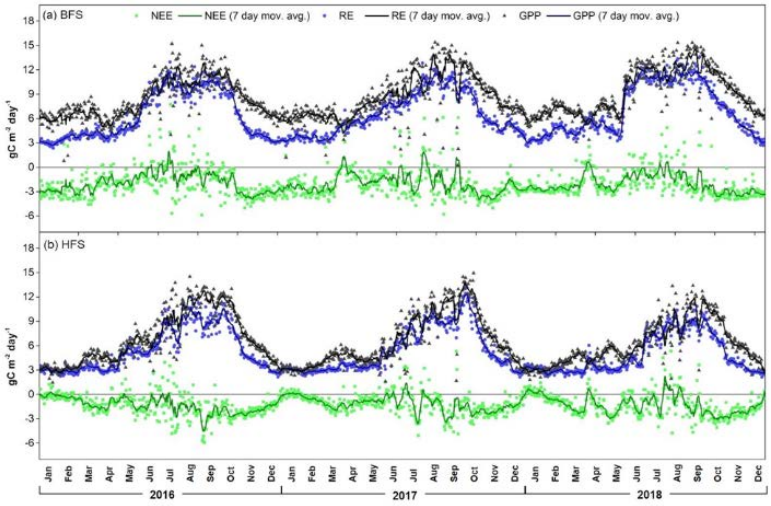


Fig 7: *Daily variability of NEE, RE and GPP observed at Barkot forest site during 2016-18*

➢ Assessment of coastal vegetation using airborne L & S band SAR data

As part of NISAR mission ecosystem science, airborne S & L band SAR data collected for mangrove ecosystem in Gulf of Khambat, Gujarat (India) were analysed for estimating the biomass. It is found that the biomass estimated using S-band SAR better depicted the biomass compared to L-band SAR. The better performance of S-band SAR is attributed to low statured and smaller diameter nature of vegetation. This study highlighted the capability of airborne S-band SAR, to be deployed in NISAR mission, in capturing information of shrubs and small- to medium-size tree vegetation.

➢ Remote Sensing for extending crop inventory to new crops

Crop discrimination of pearl millet and maize crops and crop yield modelling of cotton, sugarcane, rabi pulses in predominant production zone of respective crops have been carried out under the SUFALAM project. Temporal crop growth profile of backscatter using dual-pol Sentinel-1 and quad-pol Radarsat-2 datasets were studied to map the pearl millet crop with ~80% accuracy in Agra region (India). The maize crop was classified with accuracies of ~70% using Sentinel-1 SAR and ~77% with additional use of one-date Radarsat data. Towards yield forecasting of cotton crop in Marathwada region (India), phenology based yield model performed better (R^2 = 0.79, RMSE = 57 kg ha^{-1}) as compared to agro-spectral, *light use efficiency* (LUE) and crop simulation models. Among all four aforementioned models. Machine Learning algorithms are being used to predict the yield of sugarcane and rabi pulses with the help of historical crop yield and the temporal satellite data.

➢ Crop monitoring and estimating plant biophysical parameters using combined S and L band SAR data

In this study, S and L band SAR data are analyzed for: (i) crop discrimination in the mixed/ multi-crop; (ii) estimating plant biophysical parameters; and (iii) evaluating a Radar based index for vegetation condition monitoring for different crop vigor regions and crop types. The experimental airborne S and L-band SAR data, ALOS/PALSAR2 (L-band), Radarsat-2 and Sentinel-1 (C-band) SAR data over Bardoli (Gujarat) and Hisar (Haryana) were used to investigate their sensitivity towards crop variables. A higher dynamic range of volume scattering in L-band as compared to S-band was found across a range of *Leaf Area Index* (LAI). Assessment of crop growth parameters, *viz*. crop height and biomass for the C-band sensitive range, is addressed. Crop phenology estimation using multi-date Shannon entropy and Radar Vegetation Index from polarimetric Sentinel-1, using *multiple linear regression* (MLR) performed better than other machine learning algorithms

➢ Investigation of partial pressure of CO_2 variability over the North Indian Ocean

Since oceans absorb nearly one-third of anthropogenic CO_2 from the atmosphere, it is very important to understand how the various oceanic regions modulate the atmospheric CO_2. In order to investigate the seasonal variability of the partial pressure of CO_2 (pCO_2), *sea surface temperature* (SST) and *Chlorophyll-a* from Moderate Resolution Imaging Spectroradiometer

(MODIS)–Aqua and *sea surface salinity* from Soil Moisture Ocean Salinity (SMOS) satellite data are used to estimate the spatial distribution of pCO_2 over the NIO for a year. The Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction mooring buoy data (at 15°N, 90°E) are used for the validation of estimated pCO_2. The pCO_2 is very high over the Bay of Bengal during post-monsoon season compared to other seasons.

➢ Integrated WRF-Urban modeling for urban climate studies

Rapid urbanization is responsible for alteration in urban climate. Thus, it is required that urban climate and weather should be studied at various scales for taking into account the impact of regional phenomenon on urban climate and vice versa. The Weather Research and Forecasting (WRF) model is such a meso-scale model which has capabilities to downscale the meteorological variables up to urban scale (0.5-1 km) and also allows for multi-scale integration of urban parameters in the model. In this study, surface temperature in Chandigarh city (India) is simulated using WRF-Urban model. The inclusion of urban physics scheme provided improved forecast of meteorological variables over urban areas. Ingestion of improved urban parameterization (3-class Urban land use/ land cover) and updated land surface parameters in WRF-Urban model significantly improved the forecast of meteorological variables over urban area.

➢ Establishing relationship between urbanization and urban environment

Temporal (2007 and 2017) and seasonal (summer and winter) variations in 'urban heating' and 'urban air pollution' were analyzed using indicators like *land surface temperature* (LST), *air temperature* (AT), *aerosol optical depth* (AOD) and *particulate matter* (PM 2.5) in Delhi (India). The analysis indicates that the *surface urban heat island* (SUHI) phenomenon is observed more prominently in the nighttime as compared to daytime, with LST values in 2017 higher by 2-3 °C as compared to 2007. Similarly, *atmospheric urban pollution island* (AUPI) effect was also analysed taking *normalised difference vegetative index* (NDVI) and *normalised difference anthropogenic impervious surface index* (NDAISI) as indicators. An increase in AOD is observed from 0.4±0.27 in 2007 to 1.3±0.18 in 2017 for summers and 0.3±0.2 in 2007 to 0.7±0.18 in 2017 for winters. Statistical relations between AOD and LST, AOD and NDVI, and LST and NDVI are also studied.

➢ Multisensor integration for 3D Modeling of heritage sites

3D documentation and digital blueprinting of heritage structures provide the necessary details and information for generating heritage inventories, assessing damages/ risk and management and monitoring the built heritage sites. The study aims to improve the conventional standards of heritage information recording and documentation by utilizing geospatial technology for digital documentation of cultural sites. This study is focused on developing a methodology to integrate multi-source/ multi-platform data for: (i) improved 3D documentation of built heritage sites, (ii) generate a multi-scale hierarchical database for digital blueprinting of heritage sites, and (iii) propose a prototype framework for damage detection using point clouds and multi-scale representation for assessment and reconstruction. The UNESCO heritage sites of Humanyun's tomb, Qutub Complex and Nalanda Mahavihar have been taken up for this study.

➢ Effect of ocean subsurface temperature on track and intensity forecast of tropical cyclones

Accurate prediction of the tropical cyclones in the tropical region, particularly over the Indian subcontinent is a challenging taskIn the present study, OST representing mean temperature from surface to 50 m depth is used in the Weather Research and Forecasting (WRF) model to assess the impact on tropical cyclone track and intensity. A very severe cyclonic storm GAJA has been taken as a case study, which formed over the North Indian Ocean during November, 2018. The results revealed that OST has positive impact on the track simulation using WRF model. Similar studies were also performed for extremely severe cyclonic storm FANI and very severe cyclonic storm VAYU, originated over the North Indian Ocean in the year 2019. Positive impact of OST on track and intensity forecast of both the cyclones was found.

➢ Forest fire risk index and fire spread model development

Forest fire risk model has been developed using a combination of static and dynamic parameters *viz.*, topography, land-use/ land-cover (LULC), and fuel parameters for static and dynamic weather indices like perpendicular moisture index, fuel moisture, temperature regimes and precipitation record. The developed static and dynamic models for fire risk indices were integrated using generalized additive model to obtain the *fire danger index*. The product is a daily product and has an accuracy of 75-82%. The experimental products (https://bis.iirs.gov.in:8443/fire/composer/) are being shared with the Uttarakhand State Government during the fire season. Forest fire spread model has also been developed which uses complex network algorithm, WRF based weather forecast and Cellular Automata to model the spread of forest fire in a particular region.

➢ Geospatial solutions for enahnced governance and development

Following geospatial solutions have been developed based on specific requirement from different stakeholder departments: (i) epidemiological and entomological data collection; (ii) forest fire reporting; (iii) animal husbandry; (iv) Swachh Bharat Abhiyaan (SBA); (v) promoting the International Yoga Day campaign.

• Earth's Atmosphere and Climate

➢ Air quality monitoring and forecast system

In recent years, an increase in the poor air quality events is noted over Indian region. Particularly, Delhi and surrounding region witness severely degraded air quality during post-monsoon and pre-monsoon seasons. Considering this, an initiative to monitor the air quality of Indian region has been taken up by synergistic use of numerical prediction models for the forecasting of dust, Particulate Matter (PM 2.5 and PM 10) and gaseous pollutants (CO, O_3, SO_2, NO_2), ground based inputs, and Remote Sensing data sets of Aerosol Optical Depth (AOD) and Particulate Patter (PM 2.5 and PM 10). A Geoportal (https://airquality.iirs.gov.in) for monitoring and analysis of air quality over Indian sub-continent is developed and made available in 2019.

➢ Distribution of surface carbon monoxide over the Indian subcontinent: Investigation of source contributions

This study investigates fractional contribution of different carbon monoxide (CO) sources over the Indian Subcontinent at the surface in 2015 using a tagged tracer approach in the Weather Research and Forecasting model coupled with Chemistry (WRF-Chem). Simulated CO concentrations are also compared with CO retrieved by MOPITT (Measurement of pollution In The Troposphere) at 800 hPa and 200 hPa. At 800 hPa (200 hPa), the annual average WRF-Chem CO varies from 195±69 to 224±93 ppbv (102±25 to 136±21 ppbv) while MOPITT CO varies from 103±26 to 114±29 ppbv (103±30 to 134±33) over different Indian sub-regions. Over most of the regions, good correlation (R= >0.7) is observed between simulated and satellite observed CO. The highest contribution from anthropogenic emissions (CO-ANT) and inflow into the model domain from domain boundaries (CO-BACK) with 45-46% contribution each and very small contribution (< 5 %) of biomass burning (CO-BIOM), biogenic (CO-BIOG) emissions, and photochemical production (CO-CHEM) were found. Fractional contributions of these tracers are analyzed over different Indian sub-regions. Surface CO concentration is found to be mainly controlled by the direct anthropogenic emission in Indian megacities with a contribution exceeding 70% to CO in Delhi and Kolkata throughout the year.

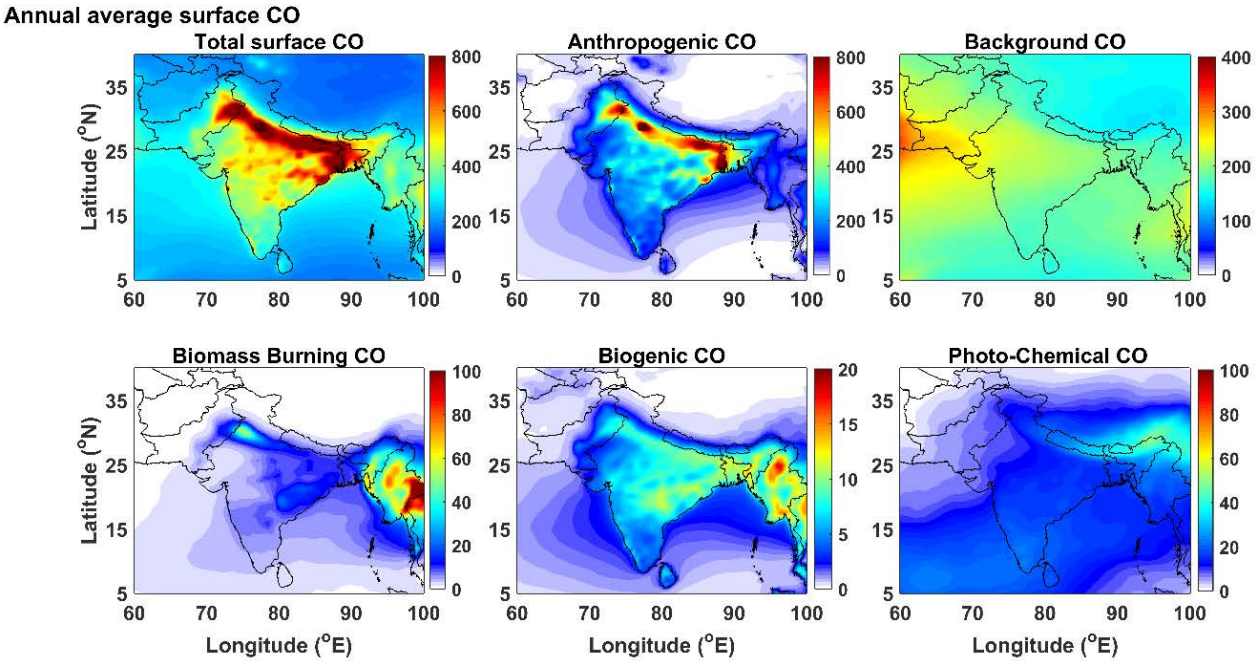


Fig 8: *Spatial distribution of annual average total CO mixing ratio and the absolute concentrations of different CO source types at the surface over the Indian subcontinent during 2015.*

➢ Study of monsoon season rainfall and extreme rainfall events over the North-West Himalayan region

Analysis of monsoon season rainfall and EREs have been carried out using satellite datasets

and numerical model for the NWH region. Model derived rainfall has been evaluated against the ground-based India Meteorology Department (IMD) gridded rainfall data and satellite-based Global Precipitation Mission (GPM) IMERGE and INSAT-3D HE-Rain. Further, assessment of various cumulus schemes has also been carried out for the simulations of ERE, and it is noted that the scale-aware cumulus scheme MSKF performs better in resolving monsoon season rainfall pattern as well as the EREs over the rugged topography of NWH region. Results obtained from the present study are useful for the improved understanding of spatial pattern of monsoon rainfall over the NWH region and extreme rainfall events forecasting.

- **Planetary Science Studies**

Geology of planetary bodies mainly, Moon and Mars have been studied using high-resolution datasets from various sensors/satellites through mineralogical, morphological, topographical analysis and age-determination of selected impact and volcanic features. Some of the important studies include: Spectral and radar based study of a permanently shadowed crater, Erlanger present at Lunar North Pole using Chandrayaan-1 data; Surface age determination of Chandrayaan-2 landing sites using Crater Size Frequency Distribution (CSFD) technique; Study of compositionally distinct lithologies at and around the Central Peaks of some recent lunar craters using data from SELENE-Kaguya, Chandrayaan-1 and LRO mission; Secondary craters around Orientale basin from Chandrayaan-2 data; Mineralogical and morphological analysis of some complex craters (Aristoteles, Tsiolkovsky) using multiple datasets; Mars Reconnaissance Orbiter-CRISM data analysis to investigate olivine-bearing lithology around Argye basin of Mars and Thermo physical properties of Mars are analysed using Mars Odyssey (MO)-THEMIS sensor at Luga Crater, a circular depression in Argyre basin on Mars. Further, preliminary data analysis of IIRS payload of selected target sites namely, Mare Fecunditatis and Mendeleev crater, was carried out. Several other such studies have been undertaken from other regions of Moon and Mars.

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TATA INSTITUTE OF FUNDAMENTAL RESEARCH
MUMBAI

The Department of Astronomy and Astrophysics-TIFR is Located in the scenic Mumbai campus. The department carries out cutting edge research in theoretical and observational astrophysics with an active interest in instrumentation. The observations are carried out using ground based facilities as well as balloon-borne and satellite-borne instruments.

TIFR astronomers played a leading role in AstroSat, India's multi-wavelength astronomy mission, with all three major and pointing X-ray instruments were built at TIFR. These instruments are Soft X-ray Telescope (0.3-8.0 keV), Large Area X-ray Proportional Counters (3-80 keV) and Cadmium Zinc Telluride Imager (15-150 keV). While the Soft X-ray Telescope is the first and so far the only X-ray telescope built in India for astronomy observations, the Large Area X-ray Proportional Counters were the largest area X-ray instrument with fast timing capabilities at the time of its launch.

Currently, Infrared astronomers at TIFR are also developing a payload for spectroscopic and imaging survey for a future Indian satellite. The Infrared Spectroscopic Imaging Survey (IRSIS) has been proposed as a payload for the small satellite program of ISRO. It is a two band near infrared spectrometer (1.7 – 3.4 μm and 3.2 – 6.4 μm) having an optic fibre IFU. The Laboratory Model of the IRSIS satellite experiment has been completed and extensively tested.

TIFR had been conducting scientific balloon flights for cosmic ray observations since 1948. The National Balloon facility was established at Hyderabad in 1969 to cater to increasing demands for balloon based observations from groups within India and abroad. TIFR balloons reach a height of about 42 km and can carry up to a ton of payload. About 500 zero-pressure balloon flights have already been conducted from the balloon facility.

The research activities carried out by TIFR Astronomy and Astrophysics during Jan 2018- June 2020 are provided below:

A. MAJOR RESEARCH IN X-RAY AND UV ASTRONOMY

- **LAXPC/AstroSat Study of mHz Quasi-periodic Oscillations in the Be/X-Ray Binary 4U 0115+63 during its 2015 Outburst**

The X-ray binary 4U 0115+63 was observed by the LAXPC instrument on October 24, 2015 during the peak of a giant outburst. Prominent intensity oscillations of 1 and 2 mHz frequency were detected during the observation. Possible models to explain the origin of the mHz oscillations were examined.

- **Thermonuclear X-ray Bursts in Rapid Succession in 4U 1636-536 with AstroSat-LAXPC**

The X-ray binary 4U 1636-536 was observed by the LAXPC instrument on February 15, 2016. The observation included seven X-ray bursts over two days, including a rare triplet having a wait time of about 5.5 minutes between the second and the third burst. Time resolved spectroscopy as well as quasi-periodic oscillation at 5 Hz were studied. However, no evidence of kilo-Hertz quasi-periodic oscillations or X-ray burst oscillations was found, perhaps due to the hard spectral state of the source during this observation.

- **AstroSat and Chandra View of the High Soft State of 4U 1630-47 (4U 1630-472): Evidence of the Disk Wind and a Rapidly Spinning Black Hole**

The X-ray spectral and timing analysis of the transient black hole X-ray binary 4U 1630-47, observed with the AstroSat, Chandra, and MAXI space missions during its soft X-ray outburst in 2016, was presented. Black hole spin was measured and a disk wind from the system was detected.

- **Observations of GRO J2058+42 during 2019 outburst with AstroSat**

GRO J2058+42, an X-ray pulsar in a Be-binary system, was studied during its outburst in April 2019. The pulsation period of 194.2201 s with a spin-up rate of 1.65×10^{-11} hz/s was measured from LAXPC data. A quasi periodic oscillation at a frequency of 0.09 Hz and its 2 harmonics were also detected. Combined analysis of SXT and LAXPC data detected cyclotron lines in its spectrum at (9.7-14.4) keV, (19.3-23.8) keV and (37.8-43.1) keV depending on the phase of the pulsar. A magnetic field of $(1.1\text{-}1.6) \times 10^{12}$ G was inferred from these lines. The magnetic field and frequency of quasi periodic oscillations were found to be consistent with the observed spin-up rate.

- **A stochastic propagation model to the energy dependent rapid temporal behaviour of Cygnus X-1**

The results from analysis of six observations of Cygnus X-1 by Large Area X-ray Proportional Counter (LAXPC) and Soft X-ray Telescope (SXT) onboard AstroSat were reported, when the source was in the hard spectral state as revealed by the broad-band spectra. The spectra obtained from all the observations could be described by a single-temperature Comptonizing region with disc and reflection components. The event mode data from LAXPC provided unprecedented energy dependent fractional root mean square (rms) and time-lag at different frequencies which were fit with empirical functions. A fluctuation propagation model for a simple geometry of a truncated disc with a hot inner region was invoked. Unlike other propagation models, the hard X-ray emission (>4 keV) was assumed to be from the hot inner disc by a single-temperature thermal Comptonization process. The fluctuations first caused a variation in the temperature of the truncated disc and then the temperature of the inner disc after a frequency dependent time delay. It was found that the model could explain the energy dependent rms and time-lag at different frequencies.

- **Broad-band reflection spectroscopy of MAXI J1535-571 using AstroSat: estimation of black hole mass and spin**

The results from AstroSat observations of the transient Galactic black hole X-ray binary MAXI J1535-571 during its hard-intermediate state of the 2017 outburst was reported. The individual and joint spectra from two simultaneously observing AstroSat X-ray instruments were systematically studied, and a number of parameter values of accretion disc, corona, and reflection from the disc in the system were probed and measured using models with generally increasing complexities. Using the broad-band (1.3-70 keV) X-ray spectrum, it was clearly shown that a soft X-ray instrument, which works below 10-12 keV, alone cannot correctly characterize the Comptonizing component from the corona, thus highlighting the importance of broad-band spectral analysis. By fitting the reflection spectrum with the latest version of the RELXILL family of relativistic reflection models, the black hole's dimensionless spin parameter to be $0.67^{+0.16}_{-0.04}$ was constrained. The reflection spectral component (RELXILL) and a general relativistic thin disc component (Kerrbb) were also jointly used, and the black hole's mass and distance were estimated to be $10.39^{-0.62}_{+0.61}\,M_{\odot}$ and $5.4^{1.8}_{-1.1}$ kpc, respectively.

- **UVIT observations of UV-Bright stars in four Galactic Globular Clusters**

TIFR astronomers performed photometric analysis of four Galactic globular clusters (GGCs): NGC 4147, NGC 4590, NGC 5053 and NGC 7492 using far-UV and near-UV filters of the Ultraviolet Imaging Telescope (UVIT) on-board AstroSat. With the help of color-magnitude diagrams (CMDs), they have identified ~150 blue horizontal branch stars (BHBs), and ~40 blue straggler stars (BSS) in the four GGCs. They studied in detail the temperature and radial distribution of BHBs and BSS for the four GGCs.

B. RADIO TELESCOPES

- **Giant Metrewave Radio Telescope, Pune (National Centre for Radio Astrophysics)**

The GMRT consists of thirty 45 m diameter antennas spread over a 28 km region. Twelve of the antennae are in a compact, quasi randomly distributed array with a diameter of about 1 km. The remaining antennas are distributed along 3 arms of length ~14 km in a Y-shaped configuration (North West, North East and South). The longest baseline is about 28 km and the shortest is about 100 m, without foreshortening. The telescope (with centre of the array at Latitude = 19.1 deg N, Longitude = 74.05 deg E) is located near Khodad village, which is about 80 km north of Pune.

The GMRT has been open to the international community of users since early 2002, via a proposal submission and approval scheme that presently runs two observing cycles in each year. Over the last 15 years of operations, the GMRT has produced several interesting new results and discoveries in different areas of astrophysics, and an average of more than 40 papers per year in international journals feature results from data obtained with the GMRT.

In March 2019, the GMRT formally completed a major upgrade of its capabilities, which has increased its frequency range to have near seamless frequency coverage from 110 to 1500 MHz and a maximum bandwidth of 400 MHz, along with improved sensitivity receivers with better dynamic range. This has improved the sensitivity of the GMRT for continuum imaging by more than a factor of three, along with a similar benefit for pulsar observations, and has also widened the span of redshifts over which the line from neutral Hydrogen from different reaches of the Universe can be observed. The upgrade is also accompanied by installation of a revamped and modern servo system on all the antennas, a new generation monitor and control system, and various improvements in infrastructural and computational facilities. Major initiatives for mitigation of radio frequency interference have also been implemented for the upgraded observatory, such as automated detection and avoidance of interference from satellite signals, and real-time excision of interference signals from the signal chain for each antenna.

Even as it was being upgraded, the GMRT was released to the global user community in a phased manner since 2017 itself, and has already started producing exciting front-line new results that are being published in international refereed journals. The work on the upgraded GMRT was accorded a major recognition in February 2020 – the Zubin Kembhavi award 2019 of the Astronomical Society of India for “Observational and Instrumentation work in Astronomy and allied fields” was awarded to ‘Team GMRT’ from NCRA.

The GMRT and the research work done using it was also highlighted in a documentary film commissioned by the American Physical Society in February 2020, which is available now on the following youtube link :

https://www.youtube.com/watch?v=FYaISoRZ8ns&list=PLGVe6BxyFHNWJ_qjFYxx6tL3dqzsPQSzn&index=7

- **Ooty Radio Telescope, Ooty (National Centre for Radio Astrophysics)**

The Ooty radio telescope (ORT) continued its program of long term monitoring of turbulence in the inner heliosphere. In addition, the recently started pulsar observations using the new backend (PONDER) were continued. This included studies of the ISM via a scattering survey of a large number of pulsars, studies of giant pulses, as well as of monitoring of glitching pulsars. It is also being used to monitor pulsars as part of the Indian Pulsar Timing Array (InPTA) program. The installation of the hardware for the Phase I of the upgraded system (OWFA) were completed, and characterization and calibration observations with this Phase I system were initiated. Software was developed for post-correlation beam forming i.e. from the calibrated visibilities produced by the correlator. A new hydrogen maser based time and frequency standard has been installed and commissioned.

- **India's participation in the Square Kilometre Array project (National Centre for Radio Astrophysics)**

The Square Kilometre Array (SKA) project is a multinational collaborative project to build the next generation global facility for radio astronomy. The SKA will be several times more sensitive than the best existing facilities in the world, and will address several outstanding fundamental key science topics in astrophysics. The SKA will also drive development of many new technologies, with considerable scope for contributions from industry : antennas, signal transport, signal processing, computing and software. India is a member of the SKA collaboration alongwith about ten other countries. The design work for the SKA Phase-1 completed in early 2020, and the construction of this phase is expected to start by mid-2021, for a period of 6-7 years.

NCRA led work on the design of the Telescope Manager work package, that was completed in 2018, in partnership with groups form 6 other SKA member countries. This has been followed with early prototyping activities that India has participated in since mid-2018. India has been provisionally identified as the lead country for the Observatory Management & Control work package (an expanded version of the Telescope Manager scope of work), and also as a participating country in the digital processing system for SKA-Low and for some areas of work in Science Data Processing and SKA-Mid receiver hardware systems. Based on this, a proposal is being finalised for submission to DAE and DST for supporting Indian participation in the SKA and joining the SKA treaty organisation.

C. Balloon Facility, Hyderabad

The Balloon Facility of Tata Institute of Fundamental Research has expertise in the field of scientific ballooning. The Balloon Facility designs, fabricates and launches various zero pressure polyethylene balloons for high altitude balloon-borne experiments with 100% payload recovery and also launches / hoists tethered balloons (Kytoons) for atmospheric boundary layer studies. The facility has an in-house balloon production facility as well as ground facilities for balloon launching and recovery operations, a control room for handling the data (telemetry) and command (tele-command) operations using S-band telemetry and balloon tracking capabilities. The zero pressure balloons designed and fabricated at Balloon Facility are mainly used in the field of Astronomy and Atmospheric sciences. The Balloon Facility has been providing its support for various balloon experiments of National and International research institutes. Recently, the Balloon Facility provided launch and recovery support to ISRO (NARL) and NASA for studying the Asian Tropopause Aerosol Layer (ATAL) during the Indian south west monsoon seasons (August-2018 and July-2019) and to SPL-VSSC for studying the turbulence and atmospheric gravity waves in the upper troposphere and lower stratospheric regions. Recently, the Balloon Facility has specially designed, fabricated and supplied two zero pressure balloons for manned flights to international user community.

1. Major facilities / instrumentation developed

a. Balloon Fabrication: 26 zero pressure plastic balloons have been designed in a customized manner for different experimenters and fabricated at Balloon Facility along with 10 kytoons, 4 oblate spheroids and 8 sounding balloons for various scientific experiments. Out of 26 main balloons, one balloon was exported to M/s Nott Technologies, USA, for conducting a long duration manned flight, one balloon was exported to M/s In.Genius, Singapore for conducting manned flight under 'First Singaporean into Space' program and one balloon for Chiba Institute of Technology, Japan for conducting atmospheric science studies.

b. Balloon Flights: 18 zero pressure plastic balloon flights were conducted during January 2018 to June 2020 from the Balloon Facility, Hyderabad. The details of the balloon launches conducted under various collaborations are mentioned below.

- Conducted a balloon experiment at TIFR Balloon Facility, Hyderabad for studying the atmospheric turbulence in stratospheric region (up to 30 km) for Atmospheric Dynamics Group, SPL-VSSC, Thiruvananthapuram.
- The TIFR Balloon Facility, Hyderabad has supported launching of various types of balloons with different atmospheric science payload configurations to NASA (USA), NARL (ISRO) and CNRS (France) during the Indian summer monsoon season under BATAL program. In this collaborative work, the Balloon Facility has launched different sizes of balloons that include small zero pressure plastic balloons and rubber balloons. The main objectives of these BATAL campaigns are to characterize the physical, chemical and optical properties of the Asian Tropopause Aerosol Layer (ATAL), which is mainly observed during the Indian summer monsoon season over India region. These measurements are compared with the CALIPSO satellite data. A total of 11 rubber balloons and 12 plastic balloon flights were conducted from the TIFR Balloon Facility, Hyderabad in 2018 and 2019 BATAL campaigns.
- Two plastic balloon experiments were conducted from the Balloon Facility under collaboration with NARL-TIFR for studying the vertical profile of aerosols over Hyderabad.
- Two far-infrared (FIR) balloon-borne experiments were successfully conducted with a heavy payload of mass 845 kg from the TIFR Balloon Facility, Hyderabad, as a part of TIFR-Japan collaboration in balloon-borne FIR astronomy and Japanese Fabry-Perot Spectrometer (FPS). This is one of the heaviest payloads flown by balloon experimenters from the Balloon Facility and is being regularly launched for studying the Galactic star-forming regions at longer FIR wavelengths (beyond 100 microns). The two experiments were conducted during summer (18th March) and winter (28th October) in the year 2018 and the balloons reached around 31.5 km altitude with float durations of 5.5 hours and 7 hours, resp ectively.
- The TIFR Balloon Facility successfully conducted a balloon experiment on 1st Feb 2018, to test a newly developed micro-satellite by students of BITS-Pilani, Goa under the project APEIRO. The main objective of this experiment was to detect and measure the cosmic radiation in the stratosphere. The payload was tested at two different float altitudes (24.8 km and 26.7 km).

c. Tethered balloon hoisting:

- Newly developed Wi-Fi routers of C-DOT, New Delhi were successfully tested at Balloon Facility under 'Bharatnet' project in December 2018 using 10 and 22 cu.m kytoons. The main aim of this project is to provide mobile communication in rural areas, last-mile communication during emergency situations (natural disasters) and to provide free Wi-Fi communication during heavy gatherings like Kumbh-Mela, etc.
- The Balloon Facility provided its support in hoisting a tethered balloon of volume 275 cu.m at NARL, Gadanki during the 2019 solar eclipse day (26th December 2019) for studying various atmospheric and aerosol / pollution parameters within the boundary layer under the influence of solar eclipse.

d. Instrumentation: the following electronic control instrumentation was developed to use in the scientific ballooning:

- FPGA based tele-command encoder and decoder were implemented and tested successfully on two different development boards. Customized decoder hardware was designed and implemented on a 6 layer PCB using SMD components and mil grade connectors. Number of pulsed commands that can be handled is twice the number of the existing MICT. Pulsed commands can also be used as data commands. Timer functionality too is included. Due to use of highly miniaturized components, thorough checks are being carried out to ensure there are no defects in the connections.
- Simulations in Proteus Design suite: The microcontroller based designs which were earlier carried out using conventional methods (program-debug-reprogram) are now being validated through simulations in proteus design suite simplifying the design process and reducing development cycle time.
- Electronics was developed to fly two transponders (XPDR) simultaneously with altitude encoder, with real time current and temperature monitoring through telemetry as well as on-board storage for offline analysis. Developed ground based ADS-B receiving system using Raspberry-pi and Software Defined Radio to monitor air-traffic on Flight-Aware's Pi-Aware software.
- Microcontroller based TFR Morse-code generator is implemented in balloon flights for data acquisition of ground based scientific instruments using Raspberry-pi based circuit design.
- Modular Integrated Command and Timer (MICT) / GSM-GPS: the number of commands that can be handled by the MICT has been increased by adding additional cards due to its modular structure. Wide input range DC-DC converter has been used; therefore, battery supply can be used efficiently. GPS also has been interfaced with MICT to program real time using GPS time. MICT can send the GPS information along with timer and command status information serially on RS232 interface. Raspberry-pi single board computer based data logging system has been developed to log MICT serial data and GSM-GPS status data along with on-board temperature, pressure and humidity data to its SD card. Microcontroller

and pressure sensor based compact and light weight one way switch has been developed to switch ON/OFF GSM-GPS system as per the desired altitude.

- 375 MHz Orbit Modem: 375 MHz transceivers (upgraded version of SD4 Modem) can be used to send or receive data from various on-board devices mainly load line tele-command system with orientation type payloads, where it will transmit command status to ground station. It can also be used as a standby command system in the balloon flight. It can be configured for different modulation schemes and data rates.
- 433 MHz license-free band KYL modem: This ultra-light weight license-free band modem was procured to use it as local telemetry to monitor status of load line command in orientation type payload. It can be used to transmit any serial data directly to ground modem at 9600 bps baud rate at 1 W power.
- Autonomous ballast dispenser: A programmable microcontroller based ballast dispenser was designed and developed as a redundant system for tele-command for ZF flights during BATAL campaigns, where the balloon floats in the coldest tropopause region where commands do not get executed at times due to cold soak of packages. This system was tested in one balloon flight during which 10 different timing plans were preloaded before launch and its operation was monitored in telemetry.

e. Major facilities:

- Top and Bottom end fittings for a long duration manned flight: Machined and fabricated 990 mm diameter top end fitting with a provision for mounting two apex valves and also machined bottom end fitting with M27 stud capable to carry 4000 kg suspended load.
- Fabricated three electrical winches and one manual winch at the Balloon Facility workshop for tethered balloons hoisting.
- Top end fittings for small plastic balloons were machined using Nylon-66 material and fabricated different sized payload frames for mounting small atmospheric science payloads during BATAL campaigns.
- Fabricated base plates for quadrafillar antennas, wooden gondola for mounting transponder and 375 MHz telemetry packages.
- Development of high strength load tapes with 500 kgf breaking strength for design and fabrication of a 5 ton payload capable plastic balloon for ‘Gaganyaan’ space capsule drop test.
- Development of small plastic balloons with oblate spheroid shape for conducting zero gravity tests on satellite payloads at URSC-ISRO.

f. Student’s balloon-borne experiments: The Balloon Facility, Hyderabad is regularly popularizing space science among school and college students and is encouraging them to design and conduct the balloon-borne experiments.

- Two balloon flights were conducted (during BATAL-2019 campaign) for Telangana Social Welfare Residential School Students (SWAEROSAT-1&2), to study cosmic radiation, ozone concentration and atmospheric parameters from various altitudes.
- The Balloon Facility provided its continuous support in launching of payloads of the students from University of Hyderabad to study concentration of the particulate matter (PM) and trace/minor gases with altitude-wise during the BATAL campaigns.
- Students from Sreenidhi Institute of Science and Technology (SNIST) launched a CubeSat named as "SREESAT-1" from the TIFR Balloon Facility, to measure atmospheric parameters such as pressure, temperature, humidity, ultraviolet and infrared radiation.
- Two oblate spheroid balloons of volume 78 cu.m were designed and fabricated using 76 microns Antrix film as shell for testing of various communication and surveillance equipments of IIT-Bombay with a payload weight of 45 kg up to an altitude of 100 meter.

g. Student's outreach programs/meetings

- Mini outreach program was conducted on 1st February 2018 for selected students including parents from various schools from Hubballi, Karnataka. The students visit to the Balloon Facility was supported by Dr. Mahesh Nalwad Foundation to participate in the Project APEIRO balloon flight of BITS Goa. The program comprised of a brief talk on various activities of the Balloon Facility, exhibition of flight equipment and accessories, demonstration of a balloon launch to motivate and inculcate the spirit of space science in the students.
- Mini outreach program was conducted on 12th February 2018 for Postgraduates and PhD students from the Department of Astronomy of Osmania University, Hyderabad. The program comprised of lab visits, and demonstration of live video of balloon launch operation.
- Hosted one day students outreach program for the students of ASTROWIN on 20th February 2019 and 20th February 2020. These programs covered of a brief lecture on various activities of the Balloon Facility, exhibition of flight equipment and accessories, demonstration of a kytoon hoisting to inspire and encourage the students in space science experiments.
- Conducted one day outreach program for Telangana Social Welfare Residential Educational Institutions Society and arranged various lab visits and balloon launch operations along with data analysis in July 2019.
- The Balloon Facility participated in the science day program of NCRA-GMRT, Khodad (Pune) during 2018-2020 and successfully hoisted colored kytoon of volume 9.9 cu.m with GPS radiosonde using motorized electrical winch. During this program, a brief information on different kinds of balloons design and fabrication, basics on meteorological measurements, balloon hoisting and high altitude balloon launch video were effectively demonstrated to the students, teachers and parents.

2. **Atmospheric science studies under collaborations:** The TIFR Balloon Facility, Hyderabad has been operating different scientific instruments under the ARFI (Aerosol Radiative Forcing

over India) project of ISRO-GBP program. The instruments operated under this project are Aethalometer for Black Carbon (BC), Multiwavelength Radiometer (MWR) for Aerosol Optical Depth (AOD). The TIFR Balloon Facility has also been using SODAR for measuring wind profile up to 250 m and Automatic Weather Station (AWS) for the measurement of ground level meteorological parameters like temperature, Relative humidity (RH), wind speed, wind direction and solar radiation etc. As a part of collaboration with NARL (ISRO), the TIFR Balloon Facility conducted balloon experiments during July 2019 using 6 stages QCM along with the NARL aerosol payloads to study the vertical profile of aerosol mass concentration and also to find out the different chemical species of aerosols in the upper atmosphere.

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INDIAN INSTITUTE OF ASTROPHYSICS

Bangalore

Indian Institute of Astrophysics (IIA), one of the premier institutes, is involved in carrying out research and development programmes primarily in Astronomy & Astrophysics and related fields. IIA was established in the year 1971 as an autonomous research Institute wholly financed by the Government of India. Presently, IIA functions under the administration of the Department of Science and Technology. With a strength of over 70 faculties (Scientists + Engineers) and a similar strength of students plus postdoctoral fellows, IIA conducts research vigorously in the fields which are broadly classified as, Sun and Solar System, Stellar and Galactic Astronomy, Extragalactic Astronomy & Cosmology, Theoretical Astrophysics & Physics, Space Astronomy and Instrumentation. A number of 1-m and 2-m class ground-based telescopes are being operated, maintained and upgraded regularly by the institute to cater to the needs of the Indian and International scientific community. IIA in collaboration with many different research institutions from India, played a crucial part in the establishment of India's first dedicated multi-wavelength space observatory called AstroSat. The institute led the development of Ultra-Violet Imaging Telescope (UVIT) on-board AstroSat.

Scientists along with the students and the postdoctoral fellows carry out frontline research using the data procured from institutional, national and international facilities to study celestial objects like the Sun, solar system objects, Population III stars, interstellar medium, molecular clouds, novae, supernovae, open & globular clusters, planetary nebulae, post-AGB stars, chemical abundance studies of stars that are at different evolutionary stages, extreme helium stars, Li-rich giants, etc. The facilities utilized include both ground-based and space-based telescopes. The images captured by the UVIT in FUV and NUV filters enabled scientists at IIA to study exortic stars in rich cluster environments and to identify star forming regions in the external galaxies.

Currently, scientists and engineers at IIA are engaged in the development of an instrument called Visible Emission Line Coronagraph (VELC) which will form one of the crucial instruments on board Aditya-L1 mission. The testing and calibration of the components are being carried out at IIA's facilities and labs. To utilize the lessons learned from the successful AstroSat mission effectively and to enlarge the footprint of Indian space astronomy in the international scene, a proposal for a 1-m class UV-Optical imaging and spectroscopic space telescope, named as Indian Spectroscopic and Imaging Space Telescope (INSIST) was submitted in April 2018. The proposal was submitted in response to a call for future astronomy missions made by the ISRO. After a review of all the proposals, INSIST was awarded seed funding, for a year of pre-project phase, in March 2019. The INSIST project has completed a conceptual design as well as a preliminary design and has reached the maturity to start the final design phase.

A. Major facilities/Instrumentation:

- **Visible Emission Line Coronagraph:**

VELC is one of the important payload on board India's first space solar mission Aditya-L1. It is an internally occulted solar coronagraph capable of simultaneous imaging, spectroscopy and spectro-polarimetry close to the solar limb. The uniqueness of the VELC is the simultaneous observations in multiple wavelength bands closer to the limb from 1.05 Rsun (Rsun is solar radius) with high pixel resolution (~2.5 arcsec & 1.5 arcsec). This payload is designed to study the coronal plasma and heating of the solar corona. Studying development, dynamics and origin of Coronal Mass Ejection (CME) and measurement of coronal magnetic fields over active regions are other important science goals. VELC is designed to image solar corona at 500 nm with an angular resolution of 5 arcsec over an field of view of 1.05 Rsun to 3 Rsun. It also facilitates simultaneous multi-slit spectroscopy at three emission lines viz Fe XIV (530.3 nm), Fe XI (789.2 nm) and Fe XIII (1074.7 nm) with a spectral resolution of 28 mA/pixel, 31 mA/pixel and 202 mA/pixel respectively, over a field of view of 1.05 Rsun to 1.5 Rsun. The payload has a dual-beam spectro-polarimetry channel for magnetic field measurements at 1074.7 nm. It is a multi-institutional project with IIA as the lead institution. Several ISRO centers such as SAC, LEOS, VSSC, URSC etc are developing various subsystems for this payload. Several of the custom designed and made optics are supplied by the LEOS, ISRO. All these are tested and characterised for their performance at Prof. MGK Menon Laboratory for Space Sciences, IIA. These include primary mirror, secondary mirror, lens assemblies etc. Several made-to-design optics such as narrow-band filters, gratings, retarders, polarisation beam displacers etc., have been procured. Many of them are of non-space qualified grade optics and had to be qualified for space applications. IIA has set up state-of-the-art test and calibration facilities for test and qualification of these optics for their use in VELC payload.

- **INSIST:**

After a review of all proposals, INSIST was awarded seed funding for a year of pre-project phase, in March 2019. Operating close to its diffraction limit, 1m-diameter INSIST will have a spatial resolution comparable to the HST, but will image in three UV-, u- and g-bands, simultaneously, covering the UV/blue-optical region with instantaneous field of view that will be nearly two orders of magnitude larger than the HST. The INSIST is expected to provide FWHM~0.15 arcsec images over the entire field area. The high-level design features and technical capabilities of the mission, which is currently base-lined as a wide-field imaging facility, with two spectroscopic capabilities: (1) a slit-less (grism) mode, and (2) a DMD-based, configurable MOS. The main science drivers for this mission span a wide range of topics, starting from evolution of galaxies in groups and clusters, chemo-dynamics and demographics of the nearby universe, stellar systems with accretions, to stars with planetary systems, to cosmology near and far. Currently, the INSIST project has completed a conceptual design as well as a preliminary design and has reached the maturity to start the final design phase. The next phase requires close coordination with the mission team to finalise various parameters such as the mass, volume, thermal, power, data

rates, orbit details etc. The INSIST team is also engaged in the development of a lab model of a spectrograph to test the working of Digital Micromirror Devices (DMD) which will be utilized in the INSIST to perform multi-object spectroscopy.

- **Balloon Flights:**

IIA also has a small payload group pioneering the use of low-cost small payloads to carry out long term mapping of the sky in the Ultraviolet. Such science cases are not feasible with large telescopes that are designed for deep observations of individual sources or regions in the sky. The high-altitude balloon experiments were primarily a testing platform for these space payloads and instruments. Over the years, this initial plan has grown to accommodate its own science interests as well. Payloads are being designed to characterize the atmosphere through observations of the emission and absorption lines of gases including trace greenhouse gasses. Through these observations and the application of models of atmospheric chemistry, it is planned to probe physical conditions in the upper atmosphere. Another payload under development is to search for microbial life in the upper atmosphere. This project, called SAMPLE (Stratospheric Altitude Microbiology Probe for Life Existence) will collect dust samples from the stratosphere and get them back to ground while ensuring adequate contamination control. Starberry Sense is a low-cost star sensor based on raspberry pi single board computer. Presently under development, it will be tested on the high-altitude balloon platform and eventually be a space worthy star sensor. The high-altitude balloon platforms are also popular with the innovative undergraduate and school students in and around Bangalore. These projects range from studying the variation of ozone with altitude to photographs from near-space to verify the curvature of earth.

- **Thirty Meter Telescope (TMT):**

India TMT, at Indian institute of Astrophysics (IIA), Bengaluru, in collaboration with a large number of Industries is making high precision hardware components and much of the software for the project. More than two dozen industries are involved in the project. Recently, India TMT/IIA completed the construction of state-of-the-art large optics fabrication facility at the Center for research in Education and Technology (CREST), campus of IIA to meet India's in-kind obligations to TIO (Thirty Meter Telescope International Observatory) for polishing of 90 mirror segments of 1.45-m diameter using stress mirror polishing (SMP) technique. During this time India TMT also completed manufacturing of 20 actuators by four different industries. India TMT also concluded a contract with L&T for supply of 100 segment support assembly. Apart from hardware India TMT continues to provide software modules as part of observatory software suite and contributing to both 1st and 2nd generation instrument development.

India's participation in the TIO will help to build National Large Optical and infrared Telescope or NLOT (~12-m diameter size) proposed to be located in Hanle, Ladakh, India at 4500m above sea level. NLOT will be based on technology used for the TMT Project.

B. Major Research

- **Results from UVIT on board AstroSat:** The UVIT is one of the five payloads on board AstroSat. While four of the five instruments on the AstroSat observe in the soft and hard X-ray bands, UVIT observes in the Ultra-Violet bands. The primary aim of the UVIT is to simultaneously image in the far Ultra-Violet (FUV; 130-180 nm) and the near Ultra-Violet (NUV; 200 −300 nm) channels over a field of ~28 arcminute diameter with an on-sky spatial resolution of <1.5 arcsec. Additional narrower bands and options for slit-less spectroscopy, with a resolution of ~80, are also provided in the UVIT.

  A study of the blue horizontal branch (BHB) population of the Globular Cluster (GC), NGC 1851, was conducted using the images acquired with the UVIT. Photometry carried out using PSF-fitting derived from the images in the two FUV and one NUV filters are used to construct color-magnitude diagrams (CMD), in combination with the Hubble Space Telescope and ground-based optical photometry. UV variability has been detected in a number of RR Lyrae stars (low-mass, typically metal poor, Population II stars that are located within the so-called classical instability strip), and a few new variables are also detected in the central region. This study show-cases the capability of UVIT, with its excellent resolution and large field of view, to study the hot stellar population in the Galactic GCs. A complete census of the BHB and blue straggler stars (BSS) within 10 arc minute radius from the center of another GC, NGC 288, was carried using the data from the UVIT. Two extreme horizontal branch (EHB) candidates, with temperatures ranging from 29,000 to 32,000 K were detected. The radial distribution of a relatively large number of BSSs suggests that the bright BSSs are more centrally concentrated than the faint BSSs and the BHB stars.

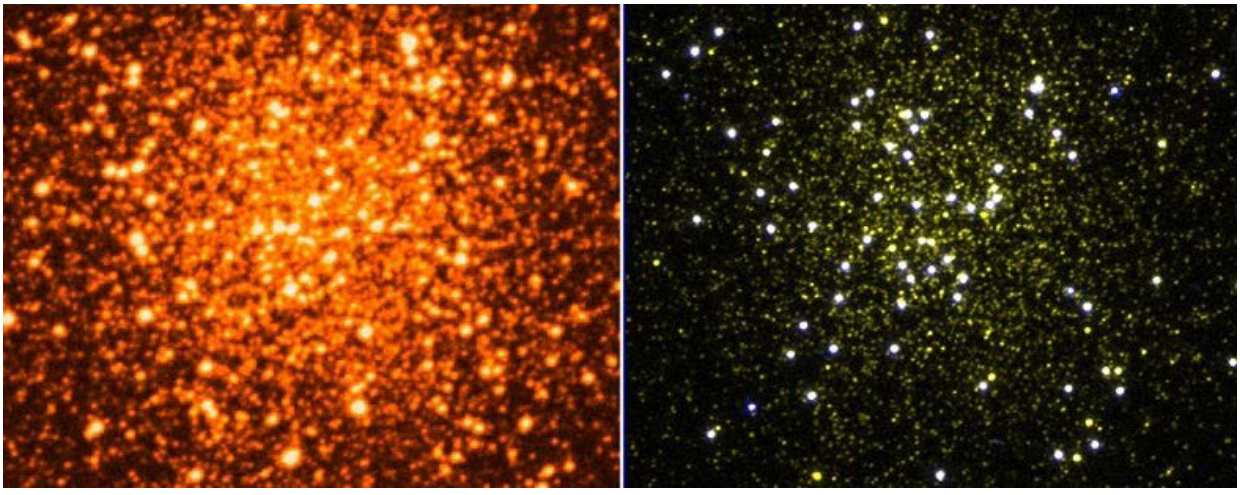

Fig 1: *The picture of NGC 288 in the optical (left side; credit: ESO/DSS) shows numerous sun-like cooler stars and it is hard to locate hot stars. The image of the same cluster in the ultraviolet (right side, taken by UVIT, yellow is the NUV and white is the FUV) shows only hot stars as the cooler stars become undetectable.*

IC2574, also known as Coddington's nebula, is located at a distance of approximately 12 million light years away and can be found in the Ursa Major constellation. IC2574 was imaged in ultraviolet using the UVIT. Many FUV bright regions were found to be located in the HI-shells, possibly created by supernovae explosions or heavy winds from OB stars. The study found that many regions in the inner parts of the galaxy are found to be associated with the shells, whereas a large number of regions in the outer galaxy are not. Star formation in the galaxy has been partly triggered due to the expanding H I holes, whereas in the majority of the sites, it is driven by other mechanisms. Irrespective of the location, larger star-forming complexes were found to have multiple substructures, an indication of turbulence. Two resolved components for the remnant cluster of the supergiant shell were reported and their masses were estimated.

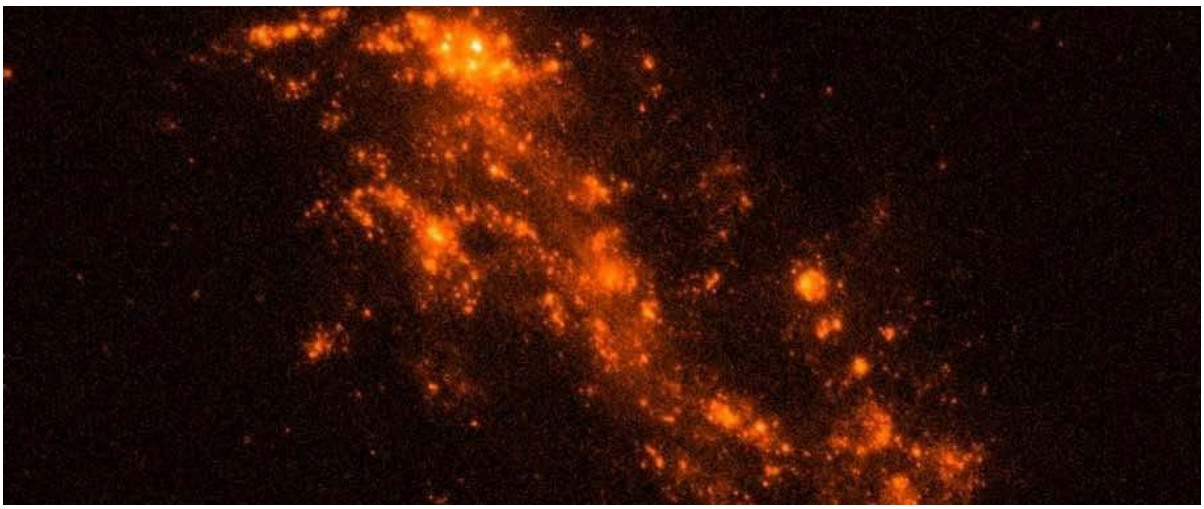

Fig 2: *The AstroSat Picture of the Month for June 2019 is the far-ultraviolet image of the Dwarf Galaxy IC2574, using ASTROSAT. The far-ultraviolet traces young massive stars in the galaxy.*

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INTER-UNIVERSITY CENTRE FOR ASTRONOMY AND ASTROPHYSICS

Pune

The Inter-University Centre for Astronomy and Astrophysics (IUCAA) is a Centre of Excellence for research in astronomy and astrophysics (A & A), and related areas. The main objectives are, besides conducting rigorous research by its own members, to provide a Centre of Excellence within the university sector for teaching, research and development in A & A, as well as to promote nucleation and growth of active groups in this area in universities. The centre enables workers from Indian universities, teachers as well as students, to visit the centre to use the facilities for various durations. New scientific results and major facilities during 2018 – June 2020 are provided below.

A. MAJOR FACILITIES/INSTRUMENTATION/PROGRAMMES

- **Computer Centre:** The Computer Centre continues to provide technology rich work space and facilities to IUCAA members, associates, and visitors. The major facilities housed in the IUCAA Data Centre currently include a 30 Teraflop HPC cluster 'Perseus' and a newly installed 60 Teraflop HPC cluster 'Pegasus' for general use. In addition, there is a 100 Teraflop HTC cluster Sarathi for Gravitational Wave data analysis. There is over a Petabyte of installed storage available for the diverse activities. The HPC clusters are being utilized for running a variety of applications including molecular scattering, molecular dynamics, stellar dynamics, gravitational N-body simulations, cosmic microwave background evolution, fluid mechanics, magneto-hydrodynamics, plasma physics, radiative transfer, stellar structure and the analysis of diverse astronomical data. IUCAA's computing facilities are accessible to the IUCAA members as well as Indian University sector for astronomy domain applications.

FIG 1: *High Performance Computing clusters, Perseus, Pegasus, and Sarathi*

- **Library:** The Library has an extensive collection of books, CDs, and research journals, that a typical research worker in A & A would need, including electronic subscription to journals. Requests for articles from researchers in India and abroad are fulfilled through e-mail or post.
- **Instrumentation Laboratory:** The Instrumentation Laboratory, in partnership with the California Institute of Technology, USA, has developed a laser guide star Adaptive Optics system, called RoBoAO, which has been demonstrated on the Palomar 60 inch telescope as well as at IUCAA Giravali Observatory. Under separate agreements with the University of Wisconsin-Madison (UW), and the University of Florida (UF), controllers have been developed for handling the operation and data acquisition from near-IR Hawaii detectors using a special ASIC, called SIDECAR. The first of these has been used in the near-IR arm of the Robert-Stobie Spectrograph, built by UW for the Southern African Large Telescope (SALT). The second controller has been used in the Canarias InfraRed Camera Experiment (CIRCE), built by UF for the 10.4 m Gran Telescopio Canarias (GTC) on La Palma.

  The laboratory is at present developing a Solar Ultraviolet Imaging Telescope for the Aditya-L1 mission of ISRO. In addition, an integral field spectrograph is being built for the 3.6 m Devasthal Optical Telescope at the Aryabhatta Research Institute of Observational Sciences (ARIES), Nainital. It has also established a collaborative programme with Caltech (USA), MPIfR (Germany), University of Crete (Greece), and NCU (Poland), as a part of which a novel, four-channel polarimeter is being designed and developed, and the same will be installed at the Skinakas Observatory (Greece).
- **Precision and Quantum Measurement Laboratory:** PQM-Laboratory is being established in IUCAA, and it will be useful for mega-science projects, such as Laser Interferometric Gravitational-wave Observatory (LIGO – India), advanced astronomical instrumentation, quantum communications, Thirty Metre Telescope, and in fundamental science research. This lab will build India's first optical atomic clock, and also train human resources, so that when the age of quantum technology comes, India is not short of skilled manpower.
- **Radio Physics Laboratory:** The Radio Physics Laboratory setup in IUCAA, in collaboration with the National Centre for Radio Astrophysics (NCRA), Pune, continued its task to train motivated science and engineering students nationwide in the use of Radio Telescope, and introduce them to Radio Astronomy Science Education.
- **Astronomy Centre for Educators:** The Astronomy Centre for Educators (ACE) has been established recently at IUCAA, with the two main constituent units, at present, being the National Resource Centre (NRC) for developing the Annual Refresher Programme in Teaching (ARPIT) for teachers, and the Teaching Learning Centre (TLC) for further developing astronomy teaching in the country with an emphasis on the higher education sector. Both the programmes are being funded by the Ministry of Human Resource Development (MHRD), Government of India, under the Pandit Madan Mohan Malviya National Mission on Teachers and Teaching Scheme.

The NRC has developed a broad-based course on astronomy and astrophysics for Annual Refresher Programme in Teaching (ARPIT), consisting of 57 videos spread across 11 modules, along with multiple-choice questions for each video, and suggestions for further readings. These videos have been offered on SWAYAM platform for college/university teachers. The modules covered a wide range of topics, which included: general theory of relativity, gravitational waves, quantum gravity, cosmology and large scale structure, galaxies and clusters of galaxies, physics of compact objects, sun, solar wind and planetary systems, observational astronomy, astronomy from archival data, time-domain astronomy, and astrostatistics. These video presentations were made by 27 resource persons from 11 institutions of higher education and research, spread across the country. They have highlighted the recent developments in the respective areas, touching upon the basic required pedagogy, and emphasising emerging areas in the field.

- **Public Outreach Programme:** School and college students are invited to visit the Muktangan Vidnyan Shodhika (Science Exploratorium) in IUCAA campus, where they discover the joy of learning science by do-it-yourself. During summer vacation, school students are invited to do week-long projects with guidance from IUCAA members. Every year, National Science Day and Open Day are celebrated, and about 10,000 visitors come to IUCAA campus, and acquaint about the activities. Similar programmes have been conducted for the school students around the rural region of IUCAA Girawali Observatory.

Fig 2: *A part of general public on the National Science Day*

- **Associateship Programme:** IUCAA has started this programme in 1990, through which, faculty members from Indian universities and colleges, along with their students may visit IUCAA and use the facilities for their research work. A visiting associate selected under this programme can visit maximum 365 days in a tenure of 3 years, as per their convenience.

- **Human Resources Development:** IUCAA has been conducting training programmes, such as Summer Schools, Vacation Students' Programmes, Refresher Courses, etc. for college and university students, and teachers. Also, numerous workshops and schools from introductory to research levels have been conducted.
- **Guest House:** IUCAA is a visitor oriented research institute, and hence a well equipped Guest House, consisting of flatlets and rooms, has been maintained. Recently, these have been augmented and upgraded. Also, there is a recreation centre, a small swimming pool, a gymnasium, etc. in the campus.
- **Auditorium and Lecture Halls:** A five hundred seat capacity, Chandrasekhar Auditorium, has been used for conferences, academic meetings, public lectures, school and college students' programmes, cultural programmes, etc. Well equipped 3 lecture halls have been used for graduate school lectures, seminars and colloquia.

B. MAJOR RESEARCH

- **Quantum Gravity:** New mathematical transformations have been devised to estimate physical quantities in Lorentzian quantum field theory from their Euclidean counterparts, and a path integral approach has been formulated to compute quantum back-reaction. Aspects of scalar field coupling to a Friedmann universe, and the production of particles in an expanding universe have been investigated in detail.
- **Cosmology and Structure Formation:** It has been demonstrated that formation of primordial black holes may result from small bumps or dips in the inflation potential of the early universe. A new cosmological estimator, called the Voronoi Volume Function, has been proposed, and shown to be a sensitive probe of galaxy evolution physics, dark matter and dark energy. It has been found that the internal properties of a dark matter halo and its correlation with large scale clustering is strongly influenced by the tidal environment. In an exploration of the nature of dark energy, it was found that phantom brane could reproduce the observed expansion history of the universe well, but predicted a different rate of growth of perturbations than in the conventional description using a cosmological constant. Properties of structures formed by an alternative form of dark matter composed of light Bosons have revealed a feature-rich dynamics and a characteristic density distribution that can be probed by future observations.
- **Observational Cosmology:** In clusters of galaxies, it was found that satellite galaxies with earlier infall tend to be red and quiescent, while the later ones were blue and star forming. From the analysis of an imaging survey carried out by the Hyper Suprime Camera (HSC) on Subaru telescope, over 550 new cases of strong gravitational lensing were identified. One of these lensed systems was used to estimate the Hubble constant, and in another case X-ray observations were used to estimate the mass of the lensing structure. Lensed quasars identified from Hubble Space Telescope observations and PANSTARRS-1 survey were also studied in detail. Study of weak lensing in the HSC survey yielded a new high precision

estimate of density fluctuations in the universe. From the study of microlensing of stars, a strong limit has been placed on the mass density of primordial black holes. Gravitational lensing was also used to estimate the mass distribution of stars in very distant galaxies.

- **Gravitational Waves:** A new method has been developed to identify optical transient counterparts of gravitational wave (GW) sources efficiently. A procedure has been introduced to estimate a map of the stochastic GW background sky using Bayesian regularization scheme. The impact caused by low magnitude regional earthquakes on GW detectors have been studied. A hierarchical strategy to search for GW signals from coalescing binaries has been proposed, and an optimal chi-square test for glitches in the data has been developed. A new source of GW in the mini creation event has been proposed.
- **Cosmic Magnetic Fields:** Numerical simulations have been undertaken to show that small scale dynamo action does not depend on the scale separation between simulation size and forcing scale. It was shown that a novel quasi-kinematic large-scale dynamo operates when the small scale one saturates. The growth rate and cycle period of the growing dynamo wave revealed new scaling relations with the shear rate, and it was found that magnetic shear current effect does not lead to dynamo growth in most cases which show a dynamo instability.

- **High Energy Astrophysics**

Polarisation measurements of the prompt emission of bright Gamma Ray Bursts detected by AstroSat operations have been presented and time resolved analysis of bright events undertaken. Detailed study of AstroSat observations of black hole binary systems revealing Quasi-Periodic Oscillation (QPO) and the dependence of the QPO properties on spectral ones were studied. For one source, the QPO frequency is shown to be just as predicted by the relativistic standard accretion disk. Further, detailed study of the energy continuum variability of black hole systems using AstroSat has been undertaken and a stochastic propagation model to explain the observations have been developed. QPOs have also been discovered using XMM-Newton and NuSTAR data.

Simultaneous observations of black hole systems in different wavebands have revealed curious dipping nature in one source, while an ionized wind has been detected in another. Very rapid millisecond correlations between X-ray and optical emission have been reported. Radio observations of pulsars have been used to study glitches, and X-ray observations were used to put constrain on any pulsed emission from a ultra-luminous X-ray source in the galaxy M81. Gamma-ray and X-ray studies have revealed that a binary is a milli-second pulsar, while pulse phase resolved spectroscopy study using AstroSat data has been undertaken. Low frequency variability in a pulsar has been discovered by AstroSat.

Detailed long term spectral evolution studies have been undertaken on Active Galactic Nuclei (AGN) to determine differences in broad and narrow line AGN and the relativistically blurred reflection has been studied for several sources. Time delays between the X-ray and UV emission

from AGN were measured and interpreted. Study of a jet dominated AGN (Blazar OJ 287) showed a soft excess in its X-ray spectrum and a delayed UV emission. Multi-wavelength study of a flare from a blazar was performed.

Flux and index distribution of blazars and X-ray binaries were quantified to reveal a log normal flux distribution and a Gaussian one for index. Detailed simulations of light curves for systems with different power spectral index were performed to test the efficiency of determining the nature of the distributions. Tidal Disruption Events (TDE), which are believed to be caused by the disruptions of stars by a super-massive black hole were studied in different wavebands.

- **Extragalactic Astronomy:**

➢ **Forming lenticular galaxies via violent disk instability**

In a new mechanism to form S0 galaxies, it has been shown that an isolated cold disk settled into rotational equilibrium becomes violently unstable leading to fragmentation and formation of stellar clumps that causes the bulge to grow and increase the stellar disk velocity dispersion optimally in less than a billion years. Subsequently, the galaxy evolves passively without any conspicuous spiral structure, finally resembling an S0 galaxy.

➢ **Formation of disk galaxies around z = 2**

Understanding the formation of disk galaxies like our Milky Way remains a challenging issue. A careful decomposition of a galaxy light distribution into bulge and disk components for a sample of galaxies with z = 1.5 - 4.0 has shown that pure disks have grown substantially - both in size and mass, while pure spheroids have not evolved much across this redshift range. There is an evidence for substantial activity for the disk formation and its growth at redshift about 2.

➢ **Narrowband H_α imaging of nearby Wolf-Rayet (WR) galaxies**

Based on the study of narrow-band H_α imaging along with archival data from GALEX, SDSS, IRAS, FIRST and NVSS surveys, it has been found that WR galaxies have experienced tidal interactions and/or mergers with low-luminous dwarf galaxy or HI cloud that most likely triggered the recent star formation in galaxies. WR systems appear to evolve in a similar fashion as normal star-forming galaxies but show distinct features due to their merging/interacting nature.

➢ **Incoherent fast variability of X-ray obscurers: The case of NGC 3783**

Variation in the absorption of X-ray radiation emitted from an AGN is a phenomenon seen in the X-ray spectra of several active galaxies. A comparative analysis of the X-ray spectrum of NGC 3783 during unobscured and obscured states has enabled one to put independent constraints on the density and location of the obscuring gas.

➢ Absorption measure distribution in AGN outflows?

The absorption measure distribution (AMD) in the X-ray outflows of Seyfert type AGN describes the distribution of absorbing column density as a function of ionization level of the gas. An investigation of a range of photoionization models against the overall shape of the AMD as observed in Seyfert galaxies has revealed that the shape of the distribution of ionized material is determined by both the spectral energy distribution of radiation that enters the material, and its density.

• Stars, Interstellar Medium and Planetary Studies

➢ Variability of interstellar lines in the direction of the Vela supernova remnant

A comparison of high-resolution SALT optical spectroscopy of stars in the direction of the Vela supernova remnant and those taken two decade earlier show changes in radial velocity (1 - 2 km/s) and/or increases/decreases in the equivalent widths over the two decades. Small-scale variations in line profiles across the face of the remnant suggest that a linear scale for interactions is a small fraction of the 40 pc size of the present remnant.

➢ Compact stars and the nuclear Equation of State (EoS)

Neutron stars are among the densest objects in the Universe. The presence of “exotic” matter could influence neutron star phenomena including mergers. A realistic study of the secular stability of neutron star merger remnants has been carried out using consistent hot and cold EoSs of dense matter. This study has found that inclusion of thermal effects reduced the maximum mass of the differentially rotating configurations and the maximum supported mass obtained depends both on the EoS and the degree of differential rotation. This study has also led to the estimation of the collapse time and threshold mass for prompt collapse for the EoSs with and without strangeness.

• Solar Astrophysics:

➢ Formation of sunspots and space weather

Two important goals of solar astrophysics are to understand the cyclic global magnetic activity of the Sun, and to make an early prediction of energetic events, such as coronal mass ejections and solar flares. These phenomena are powered by magnetic fields generated within the Sun. The sunspot formation mechanism is the missing part of the overall distributed turbulent dynamo paradigm of the solar magnetism, as in most studies the sunspot-like magnetic concentrations do not form in a self-consistent manner. This is remedied to some extent in a numerical work that shows the first hints of spot-like structures appearing spontaneously on the surface.

➢ Solar coronal heating

A study has shown the presence of chromospheric evaporation related to small transient brightenings that leads to the formation of coronal loops. Another study of thermal structure and energetics of the point-like EUV brightenings has shown that the dominant mechanism of energy loss for all the brightenings is conduction rather than radiation. Analysis of IRIS high-resolution

spectra has shown that the difference between Mg II intensities in coronal holes and quiet Sun increases with increasing magnetic flux density. A study aimed at understanding the role of Doppler motions in transferring mass and energy in an active region in the lower transition region of the solar atmosphere has been performed. Based on the LOS magnetic field observations from HMI and Si IV 1394 AA line emission recorded by IRIS, it has been inferred that the Doppler velocities in a weak field corridor has two components - a low velocity component centered near 0 km/s and a comparatively higher velocity component at around 10 km/s. It is suggested that the emission in the lower transition region comes from “Type II spicules”. The study invokes the idea of a “chromospheric wall”, associated with classical cold spicules, so as to explain the small Centre-to-Limb Variation (CLV) of flows.

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RAMAN RESEARCH INSTITUTE

Bangalore

The Raman Research Institute (RRI) is an icon that symbolizes and represents the heritage of Indian physicist and Nobel Laureate Sir C V Raman, continuing his legacy and style of qualitatively impactful research. The Institute preserves the inspirational spirit of this stalwart of Indian scientific cultural history.

The Raman Research Institute is now an autonomous research institute engaged in research in basic sciences. The Institute carries out the mandate as defined by the Governing Council and RRI Trust to be basic research with focus in niche fields of

1. Astronomy & Astrophysics including theoretical astrophysics, observational astronomy, and experimental Radio and X-ray astronomy,
2. Light & Matter Physics including cold atoms, ions, molecules, quantum communications and computing, and intense laser produced plasma,
3. Soft Condensed matter including research in liquid crystals, nano-composites, colloids, chemistry and biological physics, and
4. Theoretical Physics including General Relativity, Foundational quantum mechanics, soft matter physics, and classical and quantum Statistical Mechanics and Gravity.

The research conducted in the Astronomy and Astrophysics group at RRI can be broadly classified into four areas:

(a) ***Theoretical Astrophysics*** that involves development of analytical models and numerical simulations describing the dynamics, physical properties and underlying physical phenomena in celestial objects like stars, planets, galaxies, interstellar medium etc. Theorists also work on answering fundamental questions on the formation and evolution of the Universe, a branch of astrophysics called cosmology.

(b) ***Observational Astronomy*** on the other hand uses telescopes built across the globe to study radiation from space across the entire electromagnetic spectrum – low frequency (long wavelength) radio waves to very high frequency (short wavelength and highly energetic) gamma rays. These observations test existing theoretical models and also give rise to new questions that call for answers.

(c) ***Experimental Astronomy*** involves the *design, construction and operation of telescopes* for very specific purposes to address key unsolved problems, and are strategically located around the world and in space.

(d) ***Algorithms & Signal processing*** where a variety of methods and modelling are employed to amplify and or isolate the required astronomy signal from other foregrounds, backgrounds and unwanted interference and confusion.

A. Major Facilities/Instrumentation Developed

RRI faculties and engineers are involved in developing efficient and sensitive telescopes and associated receivers and algorithms. Developments of new methods and modelling are aimed towards extracting the signal of interest from the background. The Institute is developing and building an X-ray polarimeter (POLIX), in collaboration with ISRO, to be a payload onboard the XPoSat mission of ISRO, a first of its kind mission in the world. The POLIX instrument was conceived by RRI to measure X-ray polarization of cosmic sources. In the area of hard X-ray optics development, a dedicated new clean-room facility of 10,000 class has been constructed which is being employed for the fabrication of X-ray concentrators/optics.

In an attempt to observe the radio sky in the relatively unexplored window of very low frequencies (5-20 MHz), design and development of a very low radio frequency antenna has been undertaken. The SWAN – Indian Sky Watch Array Network – project continued developments and RRI members are working with numerous students from universities across the country towards exploring the transient sky with specialized receivers and algorithms. Efforts are also made towards building a cm-wave imaging telescope which, by use of a novel optics scheme “efficient linear array imaging”, provides good resolution, sensitivity and collection time with 70% less reflector area and easy cum cost effective manufacturing. Another telescope to search for supernova events in our galaxy, based on the One Element Interferometer scheme is also proposed by RRI faculty and is being constructed at the RRI field station in Gauribidanur.

SARAS 3 system - a system to detect the global 21cm signal - was field tested in relatively radio quiet regions of Timbaktu collective in Andhra Pradesh and at the Indian Astronomical Observatory at Hanle in Ladakh, which is operated by the Indian Institute of Astrophysics. Subsequent analysis of data has shown that the electromagnetic coupling of the antenna to ground introduces confusing structures into the measured spectra and efforts are in progress towards mitigating this coupling.

B. MAJOR RESEARCH

- **Astronomy and Astrophysics**

Major research results and capability building undertaken at the Institute in 2018-19 under appropriate subheadings is given below.

➢ Theoretical Astrophysics and Cosmology

Galactic Outflows

Collborative research by RRI has led to the deduction of a threshold energy injection rate density required to launch gaseous outflows from star forming galaxies which compares well with observations. Comparison of multi-wavelength simulations of the observational effects of cosmic rays emanating from superbubbles with actual observations has led to the identification of wind

termination shock as the site of cosmic ray acceleration. Current research efforts are towards inferring the physics behind synchrotron radio halos by comparing simulated radio maps with observations of edge-on star-forming galaxies.

Resonant transport of angular momentum in galaxies

Research in RRI have solved the long-standing problem of why the orbits of globular clusters (GCs) appear to 'stall' in the cores of dwarf galaxies, in contradiction with the predictions of Chandrasekhar's dynamical friction formula.

➢ High Energy Astrophysics

The High Energy Astrophysics group at RRI is involved in modelling the propagation of galactic and extragalactic cosmic rays with Monte Carlo simulations. They do multi-wavelength modelling of Galactic and extragalactic gamma ray sources to reveal the underlying physics of high-energy particle production within cosmic accelerators.

Research led by RRI reveals the problems in explaining the origin of ultra-high-energy cosmic rays if the highest energy cosmic rays are heavy nuclei. Another research is on the emission of quasars in which it is suggested that synchrotron cooling of two populations of accelerated electrons in each knot of the extended jets of six quasars may explain the radio to optical and the X-ray emission from these quasars. Modelling of the flaring and quiescent state of a variable Blazar using multi-wavelength data from various observatories has led to the inference that there could be multiple emission zones for the different wavelength bands along the jet axis of the Blazar. RRI research in Isotropic Gamma Ray Background has indicated of its extragalactic origin.

➢ Cosmology

Researchers in RRI used a formulation suitable for statistical detection of the redshifted 21-cm signal, it is shown that the early phase of the Epoch of Reionization, which is dominated by heating, Lyman-alpha and/or density inhomogeneity, can be studied using topological properties of the heated/Lyman-alpha coupled regions. This is also in agreement with existing numerical results. In a collaborative work, a new mechanism for the formation of supermassive blackhole is proposed. Studies of the cosmological implications of the formation of the first stellar-size black holes have provided magnitude estimates for the 21-cm signal. It is also shown that current and upcoming radio interferometers might be able to detect the neutral hydrogen H I 21 cm line, the hyperfine line of 3He II, and the H II recombination lines in the region around a growing black hole.

The EDGES collaboration had claimed detection of 21-cm signal that was at least a factor of two larger than standard theoretical predictions and had features that required evoking exotic physics to explain them. Using realistic model for foregrounds, researchers at RRI have shown that the data could be equally well explained by presence of an unmodeled, plausible systematic that had escaped their calibrations. In such a case, the data was shown to be consistent with a class of

21-cm signals predicted assuming standard cosmology, without any exotic physics.

Faculty at RRI proposed a critical dipole test based on a unique correspondence between the intrinsic monopole spectrum and the differential spectrum as an imprint of dipole anisotropy (DA) resulting from the motion of observer with respect to the rest frame of the source, that the measurements of the monopole component of the spectrum of interest should necessarily pass. Such a dipole qualifier for the monopole spectrum, when combined with reliable foreground estimation, is expected to pave way for in situ validation of spectral signatures from early epochs, which are important to presently reported and future detections of Epoch of Reionization (EoR) signal.

➢ Theoretical Studies on Quantum Gravity

A quantum theory of spacetime merges General Relativity with Quantum Theory. Such a theory could help resolve some of the fundamental puzzles about the universe, like dark energy and the black hole information puzzle, as well as resolve the singularities of General Relativity. However, merging the two theories has proved to be a very difficult task. At RRI two different approaches to this problem are currently being pursued, Loop Quantum Gravity (LQG) and Causal Set Theory (CST).

Research by RRI faculty have shown that LQG constructions can lead to propagating dynamics. This work demonstrates that LQG methods applied to the immensely more complex system of weakly coupled Euclidean Gravity can result in propagation. In CST domain, RRI researcher have analytically studied the 2d massive SJ vacuum in flat spacetime, and have found regimes in which it coincides with the standard vacuum.

➢ Observational Astronomy

Radio Astronomy

A broad-band study of the radio relic in the galaxy cluster Abell 4038 using the Upgraded Giant Metrewave Radio Telescope (uGMRT) was conducted to interpret the morphology and spectral properties of the relic in the scenario of an adiabatically compressed cocoon from the past activity of the brightest cluster galaxy in the cluster.

RRI researchers are involved along with their collaborators towards studying the variability in the properties of local pulsars and that of the intervening medium. Targeted observations to search for pulsars and fast transients are continuing at 34.5 MHz, using the Gauribidanur Radio Telescope. Efforts were also towards studying the distribution of pulsars, and assessment of underlying processes that govern their distribution. The phenomenon of subpulse drifting offers unique insights into the emission geometry of pulsars, and is commonly interpreted in terms of a rotating carousel of spark events near the stellar surface. A detailed geometric model was developed in collaborative work for the emission columns above a carousel of sparks that is entirely calculated

in the observer's inertial frame, and which is consistent with the well-understood rotational effects of aberration and retardation. In another work, detailed analysis of the drift pattern obtained through improved pulsar data analysis has suggested a system of 19 sub-beams rotating around the magnetic axis of pulsar B0809+74. Studies on the phenomena of lunar occultation were also conducted.

X-ray Astronomy

Studies of the high-resolution X-ray spectrum of an accreting X-ray pulsar has led to the detection of a multitude of iron lines including a Compton scattered component which reveals the presence of dense matter surrounding the X-ray source as well as Hydrogen-like and Helium-like lines indicative of a highly ionized surrounding medium. Studies undertaken by RRI faculty and collaborators of a transient X-ray binary pulsar in the Small Magellanic Cloud during its outburst in late 2017 has led to the detection of a Cyclotron Resonance Scattering Feature at ~5 keV in the X-ray spectrum, independent of the choice of the continuum model, which indicates a magnetic field strength of 6×10^{11} G for the neutron star. The study of X-ray reprocessing have revealed significant differences in the eclipse spectrum of different HMXBs and also in their eclipse spectra against out-of-eclipse spectra. RRI researchers and collaborators have constructed separately the composite spectra of galactic High Mass X-ray Binaries (HMXBs) and Low Mass X-ray Binaries (LMXBs) and used it to study the impact of these sources on the 21-cm signal using the outputs of N-body simulation and 1D radiative transfer. The heating due to the composite spectrum was found to be less patchy compared to power-law spectrum with a spectral index $\alpha = 1.5$, used in previous studies while the amplitude of the heating peak of large scale power spectrum, when plotted as a function of the redshift, was found to be less for the composite spectrum. Faculties at RRI and collaborators have extensively used the LAXPC onboard ASTROSAT to study cyclotron line characteristics, pulse phase variation and thermonuclear X-ray bursts in high mass X-ray binaries.

➢ Algorithms & Signal Processing

Research effort is also focused on developing methods and algorithms that would detect the required signal from background or place useful constraints on the parameter space of theoretical models. Research in signal processing during the past year has been towards mitigating radio frequency interference, data analysis techniques that subtract the foregrounds from mean spectrum to extract the global 21cm signal.

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ARYABHATTA RESEARCH INSTITUTE OF OBSERVATIONAL SCIENCES

Nainital

Aryabhatta Research Institute of Observational Sciences (ARIES) is a center of excellence for research in Astronomy & Astrophysics, Solar Physics and Atmospheric Sciences. It builds and operates state-of-the-art observational facilities to carry out research in front-line areas. It has established India's largest 3.6 m aperture optical telescope at Devasthal as a National Facility. It has established a very high frequency Radar, an international class facility to study climate action in the Stratosphere and Troposphere of earth. It builds-up a knowledge base for studying effects of anthropogenic and natural activities on the air-quality and regional climate change. It is making accessible the advanced observational instruments to the students and researchers of the country. It has strong collaborations with national, international institutions and industries to establish Research and Development Facilities. It has cutting-edge technological expertise in the country in the areas of opto-mechanical, electronics and control software. ARIES generates highly skilled PhD students in the areas of Astronomical and Atmospheric sciences.

A. Major Facilities/Instruments Developed:

- **3.6 m Devasthal Optical Telescope (DOT):** ARIES operates India's largest 3.6 m DOT as a National Facility at Devasthal, Uttarakhand. Ninety three percent time on the telescope is guaranteed for astronomers from India whereas the remaining seven percent is guaranteed for astronomers from Belgium. The DOT facility consists of a modern 3.6 m diameter optical telescope with active optics technology, a suite of complex instruments, a mirror coating plant, and a control room. The instruments can provide astronomical observations at optical and near-infrared wavelengths catering to a wide range of astronomical topics related to solar system objects, exoplanets, stars, star-clusters, galaxies and extragalactic sources. The 3.6 m DOT was commissioned in March 2016 and it has been put into regular operation since then. During 2018-20, three modern back-end instruments have been tested, characterized and commissioned.

A near-infrared imaging instrument TIRCAM2, developed jointly by TIFR and ARIES has been tested and commissioned on 3.6 m DOT. It is sensitive in the wavelength range from 1 to 3.7 microns and covers a field of view of 86.5 arcsec x 86.5 arcsec. It has broad-band J, H, K and narrow-band BrG, K-cont, PAH and nbL filters. Deep imaging observations show that the instrument has the capability to observe sources upto 19.0 mag, 18.8 mag and 18.0 mag with 10% photometric accuracy in J, H and K band respectively, with corresponding effective exposures of 550s, 550s and 1000s. Stellar images with FWHM of 0.45 arcsec in K-band were recorded in best conditions. Another highlight of this camera is the observational capability for sources upto magnitudes of 9.2 in the narrow L-band (nbL; λcen~ 3.59 microns). Sources with strong polycyclic aromatic hydrocarbon (PAH) emission at 3.3 microns can also be detected with TIRCAM2. It is permanently mounted on the side-port of the telescope.

An imaging and spectroscopy instrument namely TANSPEC for the 3.6m DOT was jointly developed by TIFR and ARIES. This has been tested and characterized on 3.6m DOT. It has sensitivity in the wavelength range from 550 to 2540 nm. It offers photometry for a field of view of 1 arcmin x 1 arcmin. In broad-band r, i, Y, J, H, K and narrow-band H2 and BrG filters. Stellar images with FWHM of 0.5 arcsec in K-band were recorded in best conditions. It is possible to detect sources at J, H, K of 19.5, 18.9, 18.4 mag respectively at 10 sigma level in 10 minutes exposure. R~23 mag source is detected in 1 hour exposure. For spectroscopy, it can be used in cross-dispersed mode (R~2750) as well as in prism mode (R~100-350). It is possible to take R ~ 2750 (~100-350) spectra of J=14.3 (17.3) mag source in 1 hour at 100-sigma level for stellar sources with FWHM of 1 arcsec.

The in-house designed and developed spectrograph ADFOSC was commissioned on the 3.6m DOT for the upcoming science observations. It is a low resolution slit-spectrograph and camera having sensitivity in the wavelength range 350 nm to 1050 nm. It covers a field of view of 13.6 x 13.6 arcmin. It offers broad-band SDSS u, g, r, i, z filters. Imaging observations show that the instrument has the capability to detect sources up to 24.5 magnitude with 10% photometric accuracy in r-band in effective exposure of about 2 hours in dark nights. Stellar images with FWHM of 0.9 arcsec in r-band were recorded in May 2020 in best sky conditions. Spectroscopic observations with the instrument show that a spectroscopic trace of g=19 mag source at 5-sigma level can be detected in 10 minutes of exposure at around 0.2 nm per pixel dispersion.

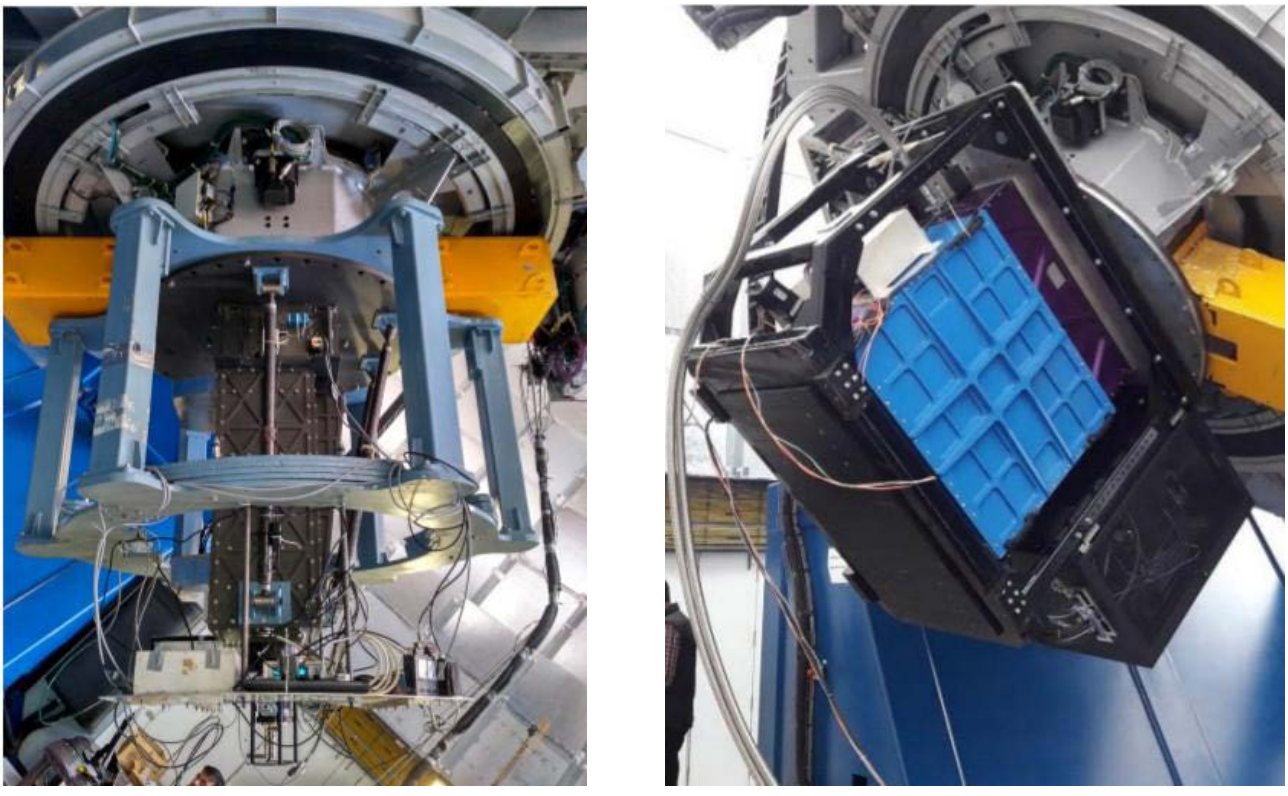

Fig 1: *ADFOSC (left) and TANSPEC (right) instruments mounted on the main axial port of 3.6 m DOT.*

- **Stratosphere Troposphere (ST) Radar:** The ST Radar system (206.5 MHz) at Manora Peak, Nainital, is configured as an Active Aperture Distributed Phased Array using state-of-the-art Solid State TR module and Digital Signal Processing techniques. This system has an array of 588 Yagis of 3 elements in a circular aperture on equilateral triangular grid arrangement. The entire system is developed in-house, and an antenna array is installed on a rooftop for the first time.

Fig. 2: *Recently installed a clutter fence along the periphery of the ST Radar antenna array on the rooftop of the building.*

During 2018-19, ARIES has operationalized 12 clusters successfully and observations have been obtained up to a height of 20 km. Radar has also been operated continuously for more than 72 hours and during this period of operation, GPS radiosondes were also launched to compare the wind products. Reasonably consistent results on winds are obtained between ST Radar and GPS radiosonde.

- **National and International collaborations**

A Memorandum of Understanding between ISRO and ARIES was signed in June 2020 for cooperation in the field of Space Situational Awareness (SSA) and Astrophysics. Space objects orbital tracking, analysis and space weather studies are important aspects in Space Situational Awareness & Management to safe guard Indian space assets from critical conjunction threats from space debris. Future endeavors in space exploration depends on R&D in Astrophysics, solar sciences and space environment. Self-reliance in these areas is key to the progress of Indian space arena. The MoU will pave the way for future collaborations between ISRO and ARIES in establishing optical telescope observational facilities for space object tracking, R&D studies in space weather, astrophysics and Near Earth Object (NEO).

Fig 3: *ISRO signs MoU with ARIES for cooperation in the field of Space Situational Awareness (SSA) and Astrophysics.*

ARIES is planning to set-up and operate a 5-year survey telescope viz 4-m International Liquid Mirror Telescope at Devasthal for a deep and high-resolution photometric and astrometric observations of astronomical sources within about half a degree strip of Devasthal sky. The augmentation of a computing cluster for theoretical work and high performing servers are essential for fast image processing and data pipeline development. In order to enhance the involvement in ISRO's ADITYA L1 space mission a user center is planned at a suitable location. ARIES is a partner in the National Large Solar Telescope and Thirty Meter Telescope Project. In an international collaboration led by Japanese scientists, ARIES plans to participate in installing 13 portable instruments for the measurement of $PM_{2.5}$ in the state of Uttarakhand. ARIES installed and commissioned instruments at Manora Peak for study of Mountain Meteorology and Climate Change.

B. Research Highlights:

- **Astronomy and Astrophysics:**

  - High sensitivity optical observations of TGSS J1054+5832, a candidate high-redshift (z=4.8+/-2) steep-spectrum radio galaxy, were carried out in r and I bands using the ADFOSC instrument on 3.6m DOT. The radio source was previously detected from GMRT, Pune at 150 MHz. The source was successfully detected in i-band with AB near about 24.3+/-0.2 magnitude. An upper limit to color (i-K) suggests youthfulness of the galaxy with active star formation.

  - Occultation of Pluto by a star on 6th June 2020 was observed with ARIES 1.3m and 3.6m telescopes in optical and near-infrared bands as part of an International Observation

Campaign. The near-infrared H-band (1.6 μm) occultation light curve of a star UCAC4 340-192403 being occulted by Pluto was recorded and a dip in the brightness of about 2 mag was measured. A detailed scientific analysis of the event is in progress.

- Several cosmic explosive phenomena, such as GRBs and Supernovae, were observed with ARIES telescopes and remarkable contribution was made towards progenitor scenarios of such events. A wide variety of supernovae, including the newly discovered class of Super Luminous Supernovae, were investigated for a detailed characterisation and estimation of explosion parameters. The first GRB with a detected TeV emission was studied.

- Intra-night optical monitoring of various classes of AGNs were carried out. Radio-quiet AGN show comparatively much lower duty cycle and low amplitude in the intra-night optical light curves. Quasi-simultaneous multiwavelength observation of blazars using various ground and space-based telescopes around the globe were carried out. Blazars show large amplitude flux and spectral variation on diverse time scales. Spectral energy distributions were explained by one or two zone leptonic models.

- In the recent study of some of the young and intermediate-age open clusters in the Galaxy suggests that many intermediate age Galactic open clusters show multiple populations of star formation and epoch of star formation varies as much as 650 Myrs. Star formation in star clusters is non-coeval and may continue for more than five Myrs. It does not cease after the formation of massive stars in the cluster. Formation of massive stars further trigger next generation of star formation at the periphery of the cluster regions.

- Eleven open star clusters have been studied to know the galactic structure and galactic motion towards their location. Their updated physical parameters are derived using the cluster members selected from kinematical data. The study shows that most of the clusters are rotating in a circular orbit around the Galaxy. Five delta scuti type and two W UMa type variable stars in four clusters were discovered. Three polars have been discovered as eclipsing polar, increasing census of long period eclipsing polar to 7 using the Indian optical telescope. The accretion geometry of an only disc-less accretor V2400 Oph is identified as disc accretor in few observations. For the first time the Wolf-Rayet star WR 121a is found to be a colliding wind binary with an orbital period of 4.1 days. Based on photometric observations of a star-forming region Cygnus, 31 variable stars were discovered in which 14 show periodic variability. Further, analysis of the Kepler space data of 170 hump and spike stars, it was found that the spikes in the frequency spectra is not strongly dependent on the appearance of star-spots on the stellar surface.

- **Sun, Atmosphere and climate:**

- Studies of solar flares and associated filament and CME eruptions using multi-wavelength ground and space-based telescopes revealed high-energy emission of seismic waves and extreme-ultraviolet (EUV) waves from the observed sources.

- For the first time, observations of light non methane hydrocarbons are made using a gas chromatograph equipped with flame ionisation detector modeling study of one of the important greenhouse gas, CO_2 showed that Ocean flux has least contribution (less than 10%) while dominance of biospheric flux is seen over fossil (> 80%) in the study region of Asia. The Methodology development MAX-DOAS, for INSAT utilization to retrieve Ozone profile is introduced by ARIES for the first time within the country.
- Recent observations from ST Radar (206.5 MHz) are used to estimate the first ever estimation on turbulence parameters, which are found to be higher than the southern Indian region. Additionally, INSAT-3D data have been used for retrieving the vertical ozone profiles over the Himalayan region for the first time. Balloon-borne measurements of temperature, water vapor, ozone and aerosol backscatter provided unprecedented insights into the Asian summer monsoon anticyclone thermal structure.
- Annual and seasonal distribution of different forms of precipitation and their association with different cloud types over the northern states of India over a decade (2007-2016) were investigated. The study indicates that nimbostratus and deep convective clouds are the main contributor of solid and liquid precipitations, respectively.
- A state-of-the-science regional climate model-based study of air quality in South Asia by 2050 projects no improvement in air pollution. Particulate matter of less than 2.5 micron size has been predicted to breach the WHO ambient air quality guidelines on an almost daily basis with generally degrading air quality. Aerosol measurements over the northern Indian region have revealed the contribution of fossil-fuel combustion and biomass (or wood) burning to degrading air quality. Intense dust storms from Thar Desert, northwest India and dust transport along the Indus and Ganges also can contribute to degradation of air quality and may alter the atmospheric stability and heating rates, thus modulating the Indian summer monsoon rainfall. The dust deposition also accelerates the melting of the Himalayan glaciers.
- Anomalous variations in VLF sub-ionospheric signal and Mesospheric Ozone prior to Nepal Gorkha Earthquakes in April-May 2015 show a strong link, indicating that simultaneous continuous observations of both VLF waves and mesospheric ozone can be considered for identification of the prior earthquake signatures in the vicinity of extreme earthquake-prone zones such as the Himalayan region. The study opens up a new dimension in lithosphere-atmosphere-ionosphere coupling during the earthquake preparation processes.

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INDIAN INSTITUTE OF TECHNOLOGY
Indore

Discipline of Astronomy, Astrophysics and Space Engineering (DAASE) at IIT Indore is a unique discipline among all IITs. It offers a dedicated platform to pursue research in astronomy, astrophysics and space science and engineering, and related areas. Since 2015 strength of this department has grown to seven permanent faculty members, one Ramanujan Faculty Fellow, one DST-INSPIRE faculty fellow and twenty-five PhD research scholars.

Under these broad domains, the faculties of DAASE are involved in cutting edge research in various topics. The faculty members are actively involved in international mega-science project the Square Kilometre Array (SKA), PLUTO code, Navigation with Indian Constellation (NavIC), ESA/JAXA BepiColombo (mission to Mercury), ESA Comet Interceptor mission, and related research. Our faculty members and students are extensively using national/international facilities like the ASTROSAT, LOFAR, uGMRT, VLA, ATCA, SWIFT, NuStar, FACT, MAGIC, NICER, XMM-Newton, Chandra X-ray Observatory, Cherenkov Telescope Array, Fermi-LAT, IceCube Neutrino Observatory, Himalayan Chandra Telescope, ESA Rosetta, NASA spacecraft observations (e.g. ACE, WIND, Van Allen Probes, GOES, THEMIS etc.) and will be actively involved in upcoming projects e.g. the Thirty Meter Telescope, the James Webb Space Telescope (JWST), EUCLID, SEAMS, Daksha, MACE and Aditya-L1 mission.

The department offers the M.Sc. degree in Astronomy and Ph.D. degrees in core areas of Astronomy & Astrophysics, Atmospheric & Space Sciences, and in Instrumentation. DAASE also offers a minor program in Astronomy & Space Sciences supporting a dynamic and rapidly growing undergraduate enthusiastic community interested in Space Research and Applications. The research activities and experimental facilities have been well supported by various extramural research and infrastructure grants both by National and International funding agencies.

The number of external sponsored projects in the discipline has shown an equally significant growth, with projects ranging from DST-SERB Early Career Research, DST-EMR and CSIR-EMR projects, ISRO-sponsored projects exploring capabilities of NaVIC, to international collaborations supported by two SPARC grants, one ASEM-DUO grant, one MATRICS and one Max-Planck Partner Group funding.

Besides, faculty members of DAASE take outreach as an extremely integral and significant part of their responsibilities. Over last few years, faculty members have conducted regular outreach events: Vigyan Samagam to popularise activities under India's mega science projects like the Square Kilometre Array (SKA), National Science Day, Solar and Lunar Eclipse Events, Popular Science lectures organized by M.P. Centre for Science and Technology, Astronomy Club events at IIT Indore, activities under Unnyat Bharat Abhiyaan, Bapu Khagol Mela (in collaboration with Nehru Planeterium, New Delhi), IAU 100 hours events and several school events across Indore.

A. MAJOR RESEARCH

- **Remote sensing of Earth's resources and environment**

The advent of satellite based remote sensing has completely changed how we understand our environment. Earth's environment and it's interaction with microwaves have significant influence in space and atmospheric studies. The interaction is the source of information for remote-sensing techniques, but is a serious concern for satellite based navigation and communication systems. Another important issue in space and atmospheric science is the flood of data from different sensors, both ground based and satellite based. The interpretation of the data not only required physical understanding of the medium, but also need sophisticated analysis techniques to handle large heterogeneous data coming in different format and with different spatial, temporal as well in various frequencies. Machine learning and Big data applications in these domain is another area of research thrust of this group. The study is directly related to the ISRO's activity and carried in collaboration with ISRO, MoES and DST.

Channel modelling at Ka band and higher frequencies is one of the research thrusts of the group. As a part of RESPOND project, the effect of rain microphysics, cloud and thunderstorm on microwave signal propagation is studied. The channel model for hilly region as well over plains were also studied. We have also demonstrated that the recently launched IRNSS satellite signals can be useful for detection and tracking of the thunderstorm system. A dynamic time warping based automated algorithm was developed for this purpose.

- **Earth's atmosphere and climate**

Aerosol-Cloud-rain Interrelation Studies: The primary focus of this work is to identify the climate change effect and the aerosol-cloud-rain interrelation and their modulating factors over India. Ground-based and satellite-measurements of cloud, rain and aerosols are used in the study. One of the major result in the mentioned period is the development of homogenous monsoon zone based on multiple rain features. This is important to quantify the possible extent of change in rain patterns over India. Rain pattern over India was investigated employing K-means clustering algorithm. The objective of the study to regionalize Indian region in homogenous monsoon zones based on multiple rain features including the extreme weather events. This will help to understand the climate change effect over different regions of India.

- **Ionosphere, Magnetosphere and Solar-Terrestrial relationship**

Space Weather:
The trans-ionospheric signal gets affected by three different effects in the 3-dimensional complex plasma layer of the ionosphere. These signals include: a) satellite downlink, b) communications from civil and military aircrafts, c) satellite-based internet, phone and TV broadcast and d) ground-based astronomical observations at radio wavelengths. In order to understand the corruptions of the signal and correct them, the ionosphere is required to be modelled accurately. Recent studies

of ionosphere have also been used to demonstrate the effect of Tsunami & earthquakes on the ionospheric electron density fluctuations due to propagation of acoustic gravity waves.

In addition, precision cosmological observations to probe the epoch 0.5 billion years after the Big Bang requires an extremely precision observations. However, the ionosphere at meter-wavelengths makes these observations extremely challenging if not impossible. Hence, studying ionosphere is also important in order to make precise low radio-frequency cosmological observations. This group is involved in probing Earth's ionosphere using two multi-constellation GNSS receivers as well as two NaVIC receivers under close collaboration with SAC/ISRO, Ahmedabad.

Recent studies from this group involves, studying impact of two events, namely the CME- and CIR-induced geomagnetic storms on the ionization over the Indian subcontinent were studied in details in terms of thermospheric and neutral composition and the electrojet strength. The study brought out the fact that even at the declining phase (lower activity) of a solar cycle, storm induced electrodynamics would have significant impact on the ionization over locations in low- and equatorial latitiudes. Besides, this group studies global ionospheric models and validate the reliability of these empirical models with respect to measured data from the Indian Navigation system, NavIC and the GNSS. The study brought out that IRI-Plas, being able to incorporate the plasmaspheric contribution of electron density into its model, matched closest with NavIC and GPS. In one of the research project, this group proposed a new parameter in terms of the IMF clock angle as a better forecast lead time (over the previously reported parameters) for geomagnetic storms with strong intensity. This group also published a systematic study to establish the utility and performance of NaVIC for study of ionosphere above the Indian subcontinent.

Lower Atmosphere:

Thunderstorm induced ionospheric disturbance is one of the major research focus in this domain. We have detected several such events over Kolkata where thunderstorms affects the ionospheric D-Layer and the position accuracy of IRNSS found to degrade because of that. In another work, we have tried to develop a CNN based model to predict the solar wind from solar image data captured by AIA. An fuzzy-based algorithm was also developed to detect the solar coronal hole regions from solar disc images of AIA. Efforts are going on to understand the physical relation between coronal hole properties with high speed solar wind.

Ionosphere modeling & Solar Wind Magnetosphere Coupling:

Members of the group is working on variability of ionosphere using geostationary satellites, GPS navigation satellite and Incoherent Scatter Radar (ISR, Arecibo). Developed an empirical model of ionospheric total electron content (TEC) over Indian region using geostationary satellite ETS-2 for quiet geomagnetic condition. TEC and post sunset ionosphere irregularity (scintillation/ESF) dependence on equatorial electrodynamics are studied under geomagnetic disturbances. Topside ionosphere above F-layer peak (250-2500 km) is studied using ISR under influence of solar

wind high-speed streams (HSss) and corotating interaction regions (CIRs), which can potentially modulate the entire ionosphere.

Also, they work on various magnetospheric topics with focus on solar wind HSSs, their impacts on auroral ionosphere, Van Allen radiation belts of the Earth - loss and acceleration process of relativistic (MeV) electrons through wave-particle interaction. Extremely intense substorms (which we call supersubstorms/SSSs) are studied that can cause geomagnetically induced currents (GICs) potentially damaging the ground-based power grids.

- **The Solar system bodies including Planetary Science**

Pattern Recognition in Space Observations :

There are some common challenges in automated detection of object. These problems are; existence of non-discrete object boundaries due to illumination and presence of non-separable background environment and the presence of noise which corrupt the original image information. The problem is more prominent for the case of space observation, due to huge distance within the Universe or to the low photon ow collected on telescope mirrors. In the domain of computer vision there exists numerous machine learning and soft computing-based automatic object detection techniques. But, none of the technique is sufficient to handle all sorts of images. Moreover, most of the techniques are not-robust for low SNR images. Fuzzy sets have been successfully used to manage all the uncertainty and ambiguity related to image processing. So, it would be another interesting study to model object detection technique in the paradigm of fuzzy logic, so as to manage the limitation of object detection methodologies in an efficient manner.

Solar system bodies:

The group is also involved on the study of cometary plasma dynamics using in situ spacecraft observations. Interaction of solar winds (space weather events) on a comet which is a non-magnetized solar system body is studied to understand the varying nature of solar coupling to solar system bodies with varying magnetospheric and ionospheric properties such as Earth, Mars, Mercury.

- **Astronomy and Astrophysics**

Compact Object Astrophysics :

The compact object astrophysics group encompasses the multi-wavelength study of black holes and neutron stars for the purpose of probing effects of strong gravity and the nature of ultra-dense matter. With the breakthrough discovery of gravitational waves, a new window has opened into the study of gravity at its strongest limits. The compact object astrophysics group is working with the observation data from multiple front-end satellite missions to put constraints on the existing theoretical models. The group is also involved in the study of thermonuclear burst from neutron stars. The connection between accretion on the thermonuclear burst ignition and burst on

accretion was examined in detail, particularly with regard to the current and future observations. The work particularly focused on how the flares during their high-intensity state, change their radiative behavior and the consequent possible impact on the stellar geometry and emission. Further investigations on broadband behavior of thermonuclear bursts and their dependence on source spectral state are being carried out using existing and new data from missions like Astrosat and NICER. The group is also involved in the observational study of Magnetars and the source XTE J1810-197 was studied.

The group is actively involved in pursuing front-end science problems involving compact objects using the broadband data from the Indian multi-wavelength mission. The astronomical objects Swift J1756.9-2508, 4U 1724-30 were studied. Research is also being carried out using advanced techniques like machine learning to scan, analyze, and interpret large volumes of data from the multi-wavelength missions. Work was also carried out in the study of ultra-luminous X-ray sources for probing the question of the missing intermediate-mass black holes and the models of super-Eddington accretion.

Additionally, the group is also involved in an investigation of the physics of pulsars across the distinctive classes- from radio to gamma pulsars, from isolated to binary pulsars. Currently, studies are being carried out to understand the broadband characteristics of the pulsed emission and related features like sub-pulse drifting, nulling etc. For this purpose, we have successfully obtained uGMRT and MwA observation times, and simultaneous observation will be carried out to probe the physics of these exotic phenomena with unprecedented sensitivity and broadband coverage.

MHD Simulations of Astrophysical Jets and Space Weather:

As part of the development team of a versatile and widely used Astrophysical code PLUTO, member of the group played an integral part in developing an Eulerian-Lagrangian Framework with an aim to bridge the interplay of physics on micro-scales with that on the macro-scales relevant for astrophysical systems. At IIT Indore, a *Max Planck Partner Group with Max Planck Institute for Astronomy, Heidelberg* has been established since June 2019, to develop a synthetic observatory of AGN jets relevant for the present era of multi-messenger astronomy. In collaboration with the Center for Space Sciences in India (CESSI), the group member have developed for the full 3D model of solar wind interaction with planetary magneto-sphere using PLUTO code with an aim to study the dynamics of planetary atmosphere as a response to variable solar wind velocity and the response of planetary magnetic field. Such simulation models have been attempted for the first time in India and would provide an ideal platform to extend them to study various phenomena related to solar environments with a specific focus on space weather modelling. These simulations will very well compliment the indigenous space-based solar Observatory - Aditya L1 - planned to be launched by ISRO.

Active Galactic Nuclei and High Energy Astrophysics:

There is no consensus in the scientific community that how such relativistic jets are launched, and how the particles in these jets are accelerated up to the highest energies. It is commonly believed that shock waves traveling downstream of the jets are responsible for the dissipation of jet energy. However, the recent detection of the minute and sub-hour-scale variability from flat-spectrum radio quasar (FSRQ) CTA 102 at gamma-ray energies challenge the current paradigm of the particle acceleration through shocks and indicate that particle might be accelerated through magnetic reconnection. Additional, recent results from multi-waveband observations of blazar Mrk 501 strongly suggest that particle might be accelerated through Fermi second-order acceleration in relativistic jets. It is believed that Fermi second-order acceleration might be taken place due to magnetic reconnection events. Moreover, recent study of AGN jets suggests that jets are probably powered by magnetic fields extracting either the energy of the accreting matter (Blandford- Payne(B-P) process) or the rotational energy of the spinning black hole itself (Blandford–Znajek (B-P) process). Recently, we discovered a rapid flare superimposed on a longer duration flare envelope giving a hint for co-spatial emission due to magnetic reconnection in the blazar. However, one of our ongoing research on AGN jets strongly suggests that jets can also be launched by Blandford–Payne process where magnetic energy has been extracted from the accreting matter. The study on high energy emission mechanisms from different galactic and extragalactic sources such as Crab Nebula and a few gamma-ray bursts were carried out.

Cosmology and Statistical Inference:

Following are some of the major research works that have been done by the CSI group at IITI:

- **Probing 21-cm bispectrum from the Cosmic Dawn (CD) -** Epoch of Reionization (EoR)***:*** So far the strategy to detect and interpret this signal from the CD-EoR has been mostly limited to the analysis of the power spectrum of the signal. However, the signal is expected to be highly non-Gaussian and the power spectrum will not be able to probe this non-Gaussianity. At the CSI group at IIT Indore, the study is carried out on different aspects of a novel signal estimator, named bispectrum, which will be able to quantify the non-Gaussianity in the signal. Presently, the group is working on constraining the source properties from the cosmic dawn using the 21-cm bispectrum, quantifying the impact of the redshift space distortions on the CD-EoR 21-cm bispectra, constraining different dark matter models using the CD-EoR 21-cm bispectrum, developing a CD-EoR parameter estimation pipeline for the upcoming SKA based on the bispectrum statistic. The group have already developed a power spectrum based faster method (called position dependent power spectrum) to estimate the non-Gaussianity in the signal in a limited manner. Additionally, 21-cm bispectrum studies have been extended to the post reionization era of the universe and it is shown that it is possible to put tighter constraints on the neutral hydrogen bias through such analysis.
- **Developing optimal estimators for the line-of-sight anisotropy in the CD-EoR 21-cm signal:** The group has developed and demonstrated the working of an optimal Fourier

estimator of the signal that can quantify the line-of-sight anisotropies present in the signal, such as the light cone effect. This estimator is known as the Multi Frequency Angular Power Spectrum (MAPS). We are working on the development of a bispectrum estimator in the same line, which will be Multi Frequency Angular Bispectrum (MABS).

- **Synergistic study of the CD-EoR with telescopes in other wavelengths:** SKA will be capable of making high definition tomographic images of the CD-EoR 21-cm signal. Once an ionized region is detected in such 21-cm images, one can do a follow-up survey of the ionized region using the telescopes working in infrared wavelengths. In a recent work, it is shown that such follow-up IR observations will help to constrain the role of early galaxies in the reionization process.

Radio Cosmology :

- **Galaxy Clusters and Large Scale Structure:** The group is involved in the study of galaxy clusters and large scale structures of the Universe. This group have been the lead in developing a high performance X-ray data analysis pipeline to construct high fidelity X-ray temperature maps and comparing with high fidelity radio observations from some of the SKA pathfinders like the uGMRT.

- **Hydrogen 21cm Cosmology:** Detection of the highly redshifted 21 cm “spin-flip” transition of the neutral hydrogen (HI) against the Cosmic Microwave Background (CMB) is considered as a promising probe for the cosmic Dark Ages ($z > 30$ or $\nu < 45$ MHz), the Cosmic Dawn ($30 > z > 15$ or 45 MHz $< \nu <$ 90 MHz), and the Epoch of Reionization ($15 > z > 6$ or 90 MHz $< \nu <$ 200 MHz). Studying the early universe ($z > 6$) through the redshifted 21 cm signal will allow us to understand the nature of the first stars, galaxies and black holes. There are two different approaches to observe this signal: (a) using large interferometric arrays at these low radio frequencies to produce statistical power spectra of the HI 21cm fluctuations (key science goal for projects like MWA, LOFAR, PAPER, GMRT-EoR and SKA1-low) and possibly using images of the HI 21cm fluctuations or (b) using a single antenna at these low frequencies to detect the “all-sky” averaged HI 21 cm signal as a function of redshift (key science goal for projects like EDGES, SARAS, DARE, LEDA, etc). Although this second approach is conceptually simpler than the radio interferometric approach, detection of this faint cosmological HI signal ($\sim$ 10−100 mK) with the single antenna-based approach needs to achieve dynamic ranges of $\sim 10^4 - 10^6$ in the presence of strong Galactic and extragalactic foregrounds ($> 10^3 - 10^4$ K). In addition, the ground-based experiments will be affected by the human-generated RFI (Radio Frequency Interferences) like the FM-band (87.5-110 MHz) which falls in the middle of this observed spectrum and the Earth’s ionosphere.

  In this research group, activities in HI cosmology involve deep observations with the uGMRT and characterising the foregrounds. Also, major progress in being made to create an end-to-end pipeline for simulation/emulation of SKA CD/EoR data processing and requirements on the precision of foreground removal and characterization in order to detect the faint cosmological signal. As one of the very early results from this group PI, it was suggested that

there is a possibility of localizing the strong foregrounds in the cylindrical power spectrum space, where there exists a region (known as EoR window) where the redshifted 21cm signal dominates over the bright foregrounds. This work laid out the new research dimension of foreground avoidance in order to detect the faint 21cm signal. The PI of this research group is currently the International SKA CD/EoR Science Working Group Co-Chair. The group is also heavily involved in developing new techniques with traditional Digital Signal Processing and Advanced Machine Learning techniques to detect cosmological faint signal amidst the sea of strong interfering foregrounds.

In order to detect signal from the Dark Ages, it is impossible to pursue the observations from the ground due to interference from the Earth's ionosphere. This was first pointed out by some preliminary work done by the group PI. Currently, this group is associated and leading the cosmology science case for an ISRO selected mission called SEAMS, which proposes to study the radio sky at frequencies lower than 30 MHz (z>45). This is pursued as a first of its kind mission dealing with collaboration with the PI from Pune University and Co-PI from IIT Indore under an LoI within this two Institutions.

Sunyaev-Zeldovich Effect in Galaxy Clusters :

The group recent research focuses on radio emission from galaxy clusters; particularly at frequencies above 1.4 GHz, in order to study mergers between galaxy clusters. The group is involved in the analysis of high-frequency (5 GHz, 9 GHz and 18 GHz) data from ATCA for the galaxy cluster MACS J0417.5-1154 and discovering the peculiar behaviour of the radio spectrum of the cluster, which was found to be at variance with earlier measurements, at a much smaller range of frequencies.

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INDIAN INSTITUTE OF GEOMAGNETISM
MUMBAI

As one of the premier organizations pursuing research in the area of geosciences in India, the Indian Institute of Geomagnetism (IIG) is engaged in basic and applied studies in Geomagnetism and allied fields. Modern Geomagnetism encompasses various disciplines of physics like fluid dynamics, space plasma physics, geophysics, aeronomy, atmospheric sciences, etc. The timescales of variation in geomagnetic field range from geologic reversal to subsecond magnetic pulsations. Internal processes, e.g., geodynamo that generates and sustains the geomagnetic field itself, are associated with the longest timescales. The short-term geomagnetic activity is driven ultimately by variability of solar activity and fluctuations in the solar wind. The study of Geomagnetism at longest timescales (e.g., geodynamo) can enhance our understanding of the planetary magnetism. On the other hand, study of short-term geomagnetic variability is a crucial component for understanding the Sun-Earth connection as well as for geophysical prospecting, earthquake precursors, satellite communication and space weather forecasting.

From its inception in 1841, geomagnetic research from the erstwhile Colaba-Alibag observatories has come a long way. Today, the Indian Institute of Geomagnetism is carrying out research in frontline areas in this field with the time and space variations in the geomagnetic field being used as diagnostic tools for understanding the internal structure of the Earth on the one hand, and the dynamics of the upper regions of the Earth's atmosphere and the magnetized Earth's space environment much higher above, on the other hand. Details of the investigations carried out during this period and highlights of some important findings are provided in the following section.

A. MAJOR SCIENCE RESULTS:

- **Atmosphere-Ionosphere coupling during a very severe cyclonic storm**

During the last couple of decades, several reports have established that atmospheric gravity waves (AGWs) generated in low pressure cyclonic system thunderstorms couple with the Earth's atmosphere-ionosphere system and create perturbations/disturbances in all the *D-, E-* and *F-*regions of the ionosphere. In a recent work the *F*-region Ionospheric perturbations associated with the Very Severe Cyclonic Storm (VSCS) Phailin with intensity ~T6.0, which occurred in the Bay of Bengal during 9-12 October 2013 were examined. This is the first report of such a kind from the north Indian Ocean region. Investigation of lightning discharge occurrences at the storm center along the cyclone track line showed that the lightning growth pattern closely follows the cyclone intensity during the initial, mature and decay stages. The total electron content (TEC) computed from the seven GPS stations showed that differential TEC (DTEC) is enhanced during VSCS days, compared to pre- and post-cyclone days. These findings show that the gravity waves generated in cyclonic thunderstorms propagate upwards couple with the upper atmosphere and modify the dynamics of the ionosphere.

- **A new 3-dimensional ionospheric model derived from Artificial Neural Networks – ANNIM**

Tracking the ionospheric variability is very important for sky wave and satellite based radio communication, navigation and surveillance applications. The ionospheric variability is greatly influenced by both solar originated processes and the neutral atmosphere origin, therefore, difficult to model and predict. In recent years, the Artificial Neural Networks (ANNs) are showing great potential to handle more complex and non-linear problems. Keeping these aspects in mind, a novel machine learning approach was adopted at IIG with a new Artificial Neural Network based global Ionospheric Model (ANNIM) to predict the 3-dimensional state of the ionosphere for any given location and time. The ANNIM predictions thus made matched well with the incoherent scatter radar and satellite *in-situ* electron density observations. Besides ionospheric predictions, this model developed at IIG can find potential applications in sky wave radio communications and broadcasting, over-the-horizon target detection, satellite based radio communications, determination of Global Navigation Satellite System (GNSS) positioning errors, etc.

- **Peculiarities of Equatorial Plasma Bubbles as manifested in optical and radio observations from ground**

The Equatorial Plasma Bubbles (EPBs), once developed, grow nonlinearly into topside ionosphere and simultaneous secondary instabilities lead to the development of shorter scale irregularities. The altitudinal growth and generation of smaller scale irregularities determines the spatio-temporal occurrence and the intensity of ionospheric scintillations at wide spectrum of radio waves and have significant implications on the GNSS/Satellite Based Augmentation Systems. A unique observational evidence for the development of shorter (3 meter) scale irregularities initially at the top of a rapidly rising EPB and their subsequent dilatory development at lower altitudes in a narrow funnel-like region had been found from the Equatorial Atmosphere Radar site in Indonesia. The large background electric fields lead to the rapid vertical rise of plasma bubble to the topside where the cascading rate of secondary instabilities is much faster compared to lower altitudes. As a result, the shorter (3 m) scale irregularities are initially developed at the top and subsequently developed at lower altitudes in a narrow funnel-like region. This mechanism is further validated with the High Resolution Bubble simulations carried out with large background electric fields. The rapid vertical growth and greater population of turbulent shorter scale irregularities at topside altitudes would have important implications on SBAS (Satellite Based Augmentation Systems) systems as that would cause much stronger L-band scintillations at low-latitudes away from the equator and at the crest latitudes of the equatorial ionization anomaly.

The first report of a rare occurrence of off-equatorial edge initiating and equatorward surging plasma depletions were observed in OI 630-nm imaging from the northern low latitude station, Ranchi. The usual depletions in the Northern Hemisphere take the shape of a tree-fork junction

feature near the south (i.e., toward the equator) in all-sky airglow images, and its branches would surge toward the north (i.e., poleward). However, an unusual event was reported on one of the nights when the airglow depletion surged equatorward and formed an inverted tree fork junction. This is another unknown facet of ionospheric irregularities that deserve attention.

- **Lithosphere-Atmosphere-Ionosphere-Coupling: Tracing the co-seismic ionospheric perturbations**

The generation of near field (~500–600 km surrounding an epicenter) co-seismic ionospheric perturbation (CIP) is mainly attributed to the coseismic crustal deformation. The azimuthal distribution of near field CIP, as recorded in GNSS-TEC, may contain information on the seismic source characteristics of rupture propagation direction and thrust orientations. However, numerous studies cautioned that before deriving the listed source characteristics based on coseismic TEC signatures, the contribution of non-tectonic forcing mechanisms needs to be examined. A 3D model to map the combined effects of the non-tectonic forcing mechanisms of geomagnetic field, GNSS satellite geometry, and ambient electron density gradient was proposed for the first time by IIG researchers. This 3D Non-Tectonic Forcing Mechanisms (NTFM) model can compute these effects at various ionospheric altitudes depending on the propagation characteristics of seismo-acoustic rays (Figure 1). The model not only successfully explains the ionospheric manifestations during seismic events occurring at different latitudes but also cautions that any correlation between the seismic source manifestations at the ground and corresponding ionospheric perturbations could be erroneous as the effects of these mechanisms are yet to be quantified. The conceived approach may assist in extracting the seismic source characteristics using space based observations and could be one of the major advancements in identifying and understanding the predictable characteristics of the earthquake system.

Global Positioning System (GPS) measured TEC is an integrated quantity; hence it is difficult to relate the detection of seismic induced ionospheric perturbations in TEC to a precise altitude. This limitation has been successfully addressed. Based on the specific satellite line of sight geometry and station location with respect to seismic source, a novel method has been developed to infer the detection altitude of CIP observed through GPS-TEC. As a result, in addition to the spatio-temporal evolution, the altitude information of the mentioned perturbations could also be derived using GPS-TEC technique. The efficacy of this method has been further extended for an extended seismic source varying simultaneously in space and time akin to the rupture of Mw 9.0 Tohoku-Oki mainshock. Based on this, the initial 60 seconds of the Mw 9.0 March 11, 2011 Tohoku-Oki seismic source has been viewed from the ionosphere to identify the distinct seismic sources along the rupture and thus the segmentation of an extended seismic source and to derive reasonably precise reflection of seismic rupture extent in the ionosphere in stipulated time. The proposed novel approach may assist in identifying the ground seismic sources entirely based on

the ensuing ionospheric perturbations which otherwise may not be well reproduced by the ground rupture process within stipulated time.

- **Magnetospheric Dynamics: EMIC waves and their role in populating the Van Radiation belts with relativistic electrons and particle injections into the inner magnetosphere giving rise to substorms**

One of the studies carried out by IIG is intended to understand the complex dynamics of the Earth's magnetospheric regions, with special focus to the Earth's Van Allen radiation belts which is a major topic of study in the international space physics community due to its complexity in terms of the particle energies, various electromagnetic waves, and wave-particle interactions. Various electromagnetic waves generated locally interact with high energy particles within the belts to either accelerate them to higher energies or scatter them to be lost in to the magnetosheath or to lower atmosphere/ionosphere. ElectroMagnetic ion cyclotron (EMIC) waves are a major candidate influencing the radiation belt particle dynamics through such wave-particle interaction processes. The correlation between EMIC waves and isolated substorm injections was identified for the first time. This explained the occurrence of dusk side EMIC waves in the absence of enhanced solar wind pressure or geomagnetic storms. Substorms are much more frequent than geomagnetic storms, however, all substorms are not found to be associated with EMIC waves. It was found that EMIC wave enhancements that are triggered by isolated injections showed associated signatures of strong magnetospheric plasma convection. The enhanced convection during injections can push more ions, more quickly and to deeper locations in the magnetosphere, leading to higher fluxes and greater anisotropies, which in turn lead to EMIC wave excitation.

Satellite observations indicate EMIC waves to be localized and of short durations lasting about ~20 minutes. However, in-situ multi-spacecraft study showed that long duration, azimuthally extended and radially narrow EMIC waves are triggered in the night side magnetosphere. This occurs during the recovery phase of a geomagnetic storm when the injected hot plasma overlap the expanding cold plasma in the plasmasphere. Such persistent EMIC waves can interact with relativistic electrons for longer time periods and hence are also shown to have higher impact on their loss from the magnetosphere.

Making use of the observational data collected from the Indian Antarctic station, Maitri, a study was performed to delineate the subpacket structure characteristics of EMIC waves.

- **Other Space Plasma Waves**

Generation of low frequency waves such as electrostatic ion cyclotron and Kinetic Alfven Waves (KAWs) have been studied in multi-component plasmas relevant to Earth's magnetosphere and solar wind. These waves are generated by electron/ion beams/velocity shears prevalent in various regions of the magnetosphere. Kinetic Alfven wave models developed were able to explain the

ultra low frequency waves upto 60mHz observed in auroral/polar cusp regions. Velocity shear could produce KAWs with larger growth than the ion beam as free energy source. These waves can provide particle acceleration as they possess finite parallel electric field. On the other hand, electrostatic ion cyclotron waves at their harmonics can provide heating of the ions (protons, helium or heavier ions) in space and laboratory plasmas.

During the period of this report, an alternate generation mechanism has also been proposed for the generation of electrostatic waves observed in the lunar wake during the first flyby of the ARTEMIS mission. The model involves multi-species plasma and uses the real parameters from observations. The nonlinear electrostatic waves (slow and fast ion-acoustic and electron-acoustic solitons) are generated by electron beams and are able to explain these waves in the lunar wake region.

Novel theories of electron holes and ion holes in superthermal space plasma have been developed. These theories will be useful to find the trapped particle distributions associated with the solitary waves observed by spacecraft.

The evolution of asymmetric electron acoustic double layers in the Earth's inner magnetosphere have been modelled through fluid simulation, which has pinpointed the role of ponderomotive force in their formation. For the first time, the fluid simulation-based evidence of the soliton-type behavior of supersolitary waves in plasma was delivered.

- **Solar Activity studies**

A weakening in the energy coupling parameter for solar cycle 24 was reported during this period of report that resulted in substantial (15%–38%) decrease in average strength of high, low and equatorial current systems in comparison with solar cycle 23. Overall, this study indicates a significant step down in various energies at Sun, Earth's bow-shock, and near Earth environment for current SC 24, which will have important implication on our Earth's atmosphere-ionosphere-magnetosphere system.

A new model was developed to forecast the peak sunspot activity of the upcoming solar cycle. This model suggest that the peak smoothed Version II sunspot number of solar cycle 25 would be close to 137±24.

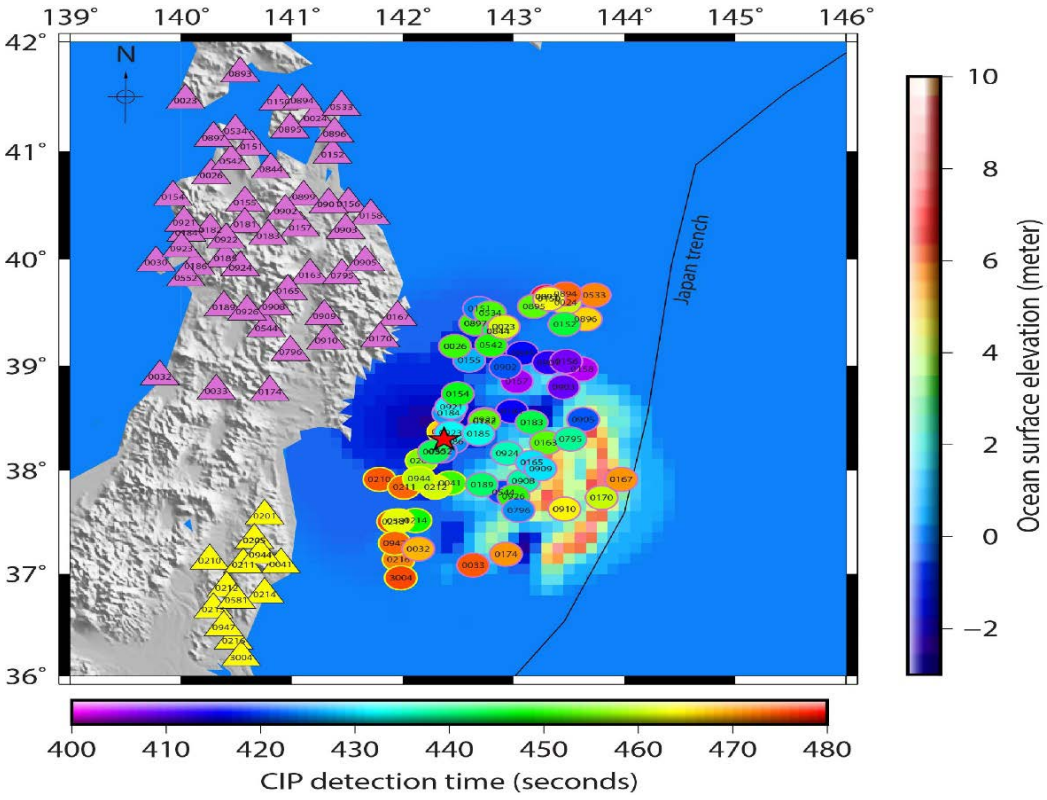

Fig. 1: *2D manifestation of Geomagnetic field - Neutral wave orientation Factor (GNF), Electron Density Factor (EDF) and Satellite Geometry Factor (SGF) and their collective effects as NTFM factor at ionospheric altitude of 350 km for the Trial seismic source (top). 3D manifestation of NTFM factor for the Trial source (bottom). The figure is prepared using the GMT 5.4.4.*

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INDIAN INSTITUTE OF SCIENCE EDUCATION AND RESEARCH
KOLKATA

Indian Institutes of Science Education and Research (IISERs) were established as autonomous institutes for higher education by the Ministry of Education, Government of India, to promote high quality education and research in basic science. The first two institutes, under this initiative, are IISER Kolkata and IISER Pune in 2006, followed by IISER Mohali in 2007, and IISER Bhopal and IISER Thiruvananthapuram in 2008, IISER Tirupati in 2015 and IISER Berhampur in 2016. One of the major objectives has been to integrate quality teaching with curiosity needed for state-of-the-art research. Teaching and research have both been very important components in the growth of IISERs. IISER Kolkata has completed more than ten years of its existence and has established excellence in science in form of teaching, publications, both in terms of quality and quantity. IISER Kolkata has Integrated BS-MS, MS, Integrated PhD and PhD programs. The Institute has a flexible academic programme and hosts state-of-the-art research facilities. Currently, it has five academic departments (Biological Sciences, Chemical Sciences, Earth Sciences, Mathematics & Statisticsand Physical Sciences) and several centres.

The Center of Excellence in Space Sciences India (CESSI) is a multi-institutional Centre at IISER Kolkata which is engaged in space science research of relevance for the nation, ISRO and COSPAR. CESSI faculty are drawn from IISER Kolkata, IISER Pune, Indian Institute of Astrophysics (Bangalore), Udaipur Solar Observatory-Physical Research Laboratory (Udaipur) and the Indian Space Research Organization (Bangalore) andIIT Gandhinagar. Theyhave wide-ranging interests in the astrophysical space sciences, and have the experience of handling international and national space science projects.

A. Summary of Space Research Activities

Space research activities at IISER Kolkata are carried out at CESSI. CESSI explores the Sun's activity, generates the understanding necessary for space weather forecasting, hunts for gravitational waves, supports national space science initiatives, and participates in international and national capacity building activities in space sciences. The Centertakes advantage of high-performance computing facilities, cloud computing and the high-speed National Knowledge Network grid to achieve its goals.

Since its inception CESSI has already contributed to major developments in astrophysics and space sciences. Notably, CESSI personnel are associated with the recently approved Aditya-L1 mission - India's first space mission to study the Sun. CESSI personnel contributed to the first direct detection of astrophysical gravitational waves from a binary Black Hole merger system and are involved with the LIGO-India mega project which aims to deploy a third gravitational wave

detector in India to supplement the observations from the two detectors in the United States of America.

CESSI faculty have developed the first India specific modelling expertise to forecast the Sun's coronal magnetic field structure which generates space weather, and they have also played a role in the development of computational models to explore the interaction of solar activity with planetary magnetospheres and atmospheres. CESSI faculty are also playing important roles in national and international capacity building through their roles in working groups and committees at the International Astronomical Union (IAU), Committee on Space Research (COSPAR), Scientific Committee on Solar-Terrestrial Physics (SCOSTEP), Astronomical Society of India (ASI) and the Indian Space Research Organization (ISRO).

B. MAJOR RESEARCH

- **Ionosphere, Magnetosphere and Solar-Terrestrial Relationship**

CESSI's work focuses on understanding the origin of solar activity driven by its internal magnetohydrodynamic dynamo mechanism, the emergence and evolution of magnetic structures on the solar surface, the structuring and dynamics of the Sun's corona, the initiation and propagation of solar storms such as flares and coronal mass ejections (CMEs) and the impact of magnetized solar plasma winds on planetary atmospheres and magnetospheres. CESSI has made fundamental contributions in this domain in 2018-2019. Some major contributions are the first century-scale calibrated, data driven model-based forecast for sunspot cycle 25, which allows prior determination of decadal scale space weather conditions development of a novel methodology for predicting the Sun's coronal magnetic fields about a month in advance and successful predictions of the Sun's coronal structure during eclipses and the development of a Star Planet Interaction module that can simulate the interaction of magnetized stellar wind plasma with planetary magnetospheres. In this period, CESSI also explored the origins of energetic solar storms known as CMEs and established connections between the magnetic properties of their solar source regions and the kinematic properties of these storms.

- **Astronomy and Astrophysics**

One of the major goals of CESSI is to facilitate IISER Kolkata's involvement in the international LIGO collaboration. CESSI personnel play critical roles in this collaboration in devising methodologies for gravitational wave data analysis and in testing Einstein's general theory of relativity. This year, among the many contributions in this domain, two stand out. The work utilized the LIGO discovered merger of a binary neutron star system to extract bounds on modified dispersion of gravitational waves, effects of large extra dimensions, and polarization content in the waves to conclude that these constraints are explained well by general relativity. The second work presented the first measurement of the Hubble's constant based on a dark siren – namely a binary black hole merger event. The Hubble's constant is a fundamental parameter in cosmology that measures

how fast the Universe is expanding at different distances from the observer. This work highlights the exciting new opportunities opened up by multi-messenger astronomy – wherein, gravitational wave observations were combined with photometric redshift measurements from the Dark Energy Survey to provide an independent measurement of the Hubble's constant.

C. Major Facilities and Instrumentation

CESSI faculty are involved in the planning and development of payloads for the Aditya-L1 space mission, which is India's first dedicated solar observatory. The Center faculty were also involved in site characterization and planning for the deployment of the Indian arm of the LIGO detector (i.e., LIGO-India).

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RESEARCH ACTIVITIES AT OTHER INSTITUTES AND UNIVERSITIES

This chapter deals with the research activities at various Universities

CHAPTER 21.1

DEPARTMENT OF PHYSICS BANARAS HINDU UNIVERSITY VARANASI

Department of Physics, Institute of Science, Banaras Hindu University (BHU), Varanasi has heritage in Atmospheric and Space Science Research from last few decades. Active research activities have been carried out at the Department of Physics in Atmospheric Physics, Space Physics and Astrophysics. A brief summary of the recent activities during the period Jan 2018-June 2020 are listed below:

A. MAJOR FACILITIES / INSTRUMENTATION DEVELOPMENT

The Atmospheric Research Laboratory, Detector Development Laboratory and Molecular Astrophysics laboratory are three major laboratories in Department of Physics, BHU which are equipped by various space research facilities. The Atmospheric Research Lab. is equipped with two GPS receivers (One Trimble 7400 and one GSNN Receiver), a VLF receiver: Automatic whistler detector (AWD) for ionospheric and magnetospheric studies. For study of atmospheric aerosol and radiative forcing in Indo-Gangatic basin, a pair of MICROTOPS-II: Sunphotometer and Ozonometer, three High Volume Air samplers: PM_{10}, $PM_{2.5}$ and $PM_{1.0}$, a Net Radiometer, an Anthalometer are purchased and installed in the Department. Currently four major research projects based on Space Physics are running in our department funded by ISRO, SERB, and DST.

Detector Development group at Banaras Hindu University has been involved in developing a gaseous-based photon detector consisting of a photocathode and micro-pattern detector such as GEM (Gaseous Electron Multiplier) for High Energy Physics research. Presently, group is also involved to extend this technology for space science research. In this program, we have been studying a variety of detector simulation tools in order to optimize the various detector performance parameters etc.

Recently a new development of an experimental facility to study infrared spectra of molecules, specifically PAHs in the gas phase has been initiated. Procurement of major instrument has been done. Accessories related to the experimentation is still being procured and developed in-house.

B. MAJOR RESEARCH

- **ATMOSPHERE AND CLIMATE**

➢ **Assessment of two intense dust storm characteristics over Indo – Gangetic Basin and their climatic implications: a case study:**

The present study is focused to examine the impacts of two intense dust storms on aerosol characteristics and their climatic implications, occurred in pre-monsoon season of 2018 (i.e. 17 May and 14 June 2018) over Kanpur (26.51^0 N, 80.23^0 E, 123 above msl). Moderate Resolution Imaging Spectroradiometer (MODIS) true colour images (Figure 1), trajectory pathways of dust storm along with satellite observation and AErosol RObotic NETwork (AERONET) measurements confirms that both the dust storms are either originated from or transported over the Thar Desert, causing a higher aerosol loading which spread over entire IGB and modifying the aerosol optical (i.e. aerosol optical depth, angstrom exponent, refractive index etc.), physical (i.e. size distribution) and radiative properties (i.e. single scattering albedo, asymmetric parameter). The space-borne Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) - retrieved aerosol measurements reveal the presence of elevated dust/polluted dust aerosol (up to 3 – 5 km) over IGB which is well corroborated with aerosol characteristics observed by MODIS, Ozone Monitoring Instrument (OMI) and Atmospheric Infrared Sounder (AIRS). The Dust Regional Atmospheric Model (BSC-DREAM8b) shows a good agreement with satellite retrievals with higher value of surface dust concentration in the range of 320 – 640 μg/m^3 over Kanpur during the dust storm days. An enhancement in monthly mean outgoing longwave radiation (up to 60 Wm^{-2}) is observed over IGB and downwind flow region during the dust storm days. The atmospheric aerosol radiative forcing is found 124 Wm^{-2} and 84 Wm^{-2} during both the dust storm days (17 May and 14 June 2018) associated with heating rate 2.69 K day^{-1} and 1.84 K day^{-1} respectively which may be significant to affect the regional atmospheric dynamics and hence the climate system also.

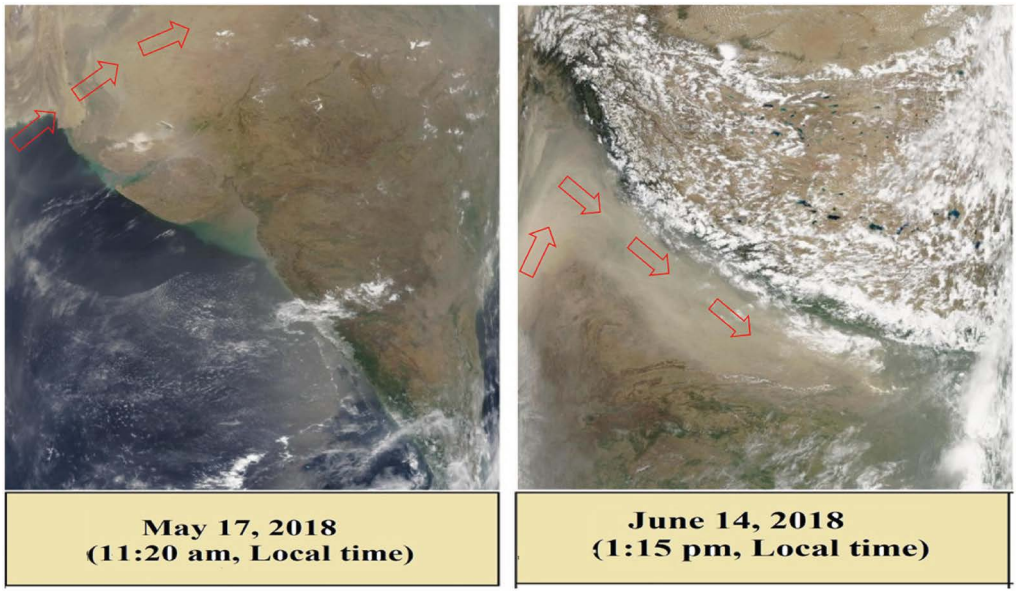

Fig 1: *MODIS TERRA and AQUA images showing long range transport of dust storms. The white colour exhibits clouds. The dust is shown in pale beige colour.*

➢ Elevated Black Carbon Concentrations and Atmospheric Pollution around Singrauli Coal-Fired Thermal Power Plants (India) Using Ground and Satellite Data:

The tropospheric NO_2 concentration from OMI AURA always shows high concentrations of NO_2 at a few locations in India, one of the high concentrations of NO_2 hotspots is associated with the locations of seven coal-fired Thermal Power plants (TPPs) in Singrauli. Emissions from TPPs are among the major sources of black carbon (BC) soot in the atmosphere. Knowledge of BC emissions from TPPs is important in characterizing regional carbonaceous particulate emissions, understanding the fog/haze/smog formation, evaluating regional climate forcing, modeling aerosol optical parameters and concentrations of black carbon, and evaluating human health. For the first time, this study reports BC concentrations and aerosol optical parameters near dense coal-fired power plants and open cast coal mining adjacent to the east IGP. In-situ measurements were carried out in Singrauli (located in south-east IGP) at a fixed site about 10 km from power plants and in transit measurements in close proximity to the plants, for few days in the month of January and March 2013. At the fixed site, BC concentration up to the 95 μgm^{-3} is observed with strong diurnal variations. BC concentration shows two maxima peaks during early morning and evening hours. High BC concentrations are observed in close proximity to the coal-fired TPPs (>200 μgm^{-3}), compared to the outside domain of our study region. Co-located ground-based sunphotometer measurements of aerosol optical depth (AOD) show strong spatial variability at the fixed site, with AOD in the range 0.38–0.58, and the highest AOD in the range 0.7–0.95 near the TPPs in transit measurements (similar to the peak of BC concentrations). Additionally, the Angstrom exponent was found to be in the range 0.4–1.0 (maximum in the morning time) and highest in the proximity of TPPs (~1.0), suggesting abundance of fine particulates, whereas there was low Angstrom exponent over the surrounding coal mining areas. Low Angstrom exponent is characterized by dust from the unpaved roads and nearby coal mining areas. The CALIPSO derived subtypes of the aerosol plot shows that the aerosols over Singrauli region are mainly dust, polluted dust, and elevated smoke. This preliminary study suggests that long-term continuous monitoring of BC is needed to understand the BC concentrations and aerosol optical properties for better quantification and the estimation of the emission to evaluate radiative forcing in the region.

➢ BATAL: The Balloon measurement campaigns of the Asian Tropopause Aerosol Layer:

A series of field campaigns conducted using balloon-borne instruments launched from India and Saudi Arabia during summers 2014-2016 to study the impact of the Asian Summer Monsoon (ASM) on aerosols in the Upper Troposphere and Lower Stratosphere (UTLS). Total 55 balloons were launched from 4 locations, one in Saudi-Arabia and 3 in India, with payload weights from 1.5 kg to 50 kg, to measure meteorological parameters, ozone, water vapor, and aerosol backscatter, concentration, volatility and composition in the UTLS region. New flight controlled systems to probe the UTLS for longer periods of time were tested. The BATAL project has been a successful partnership between institutes in the United States, Europe, India and Saudi Arabia. The BATAL project will continue for the next 3-4 years and the results gathered will be used to formulate a future NASA-ISRO airborne campaign with NASA high altitude aircraft to study the Asian Tropopause Aerosol Layer (ATAL).

➢ Aerosol characteristic and their heterogenious behaviour over Varanasi: a semi urban location in central Indo Gangetic Basin:

The study was conducted to analyze first time the regular MICROTOPS sunphotometer measurements for long term from January 2011 – December 2014 over Varanasi (25.2 N and 82.9 E, ≈ 83mmsl) and to examine the variability of aerosol on different temporal scale. The seasonal frequency distribution study is also conducted to understand the heterogeneity in aerosol concentrations. This is the first-time study over Varanasi to understand the seasonal variation in aerosol properties and heterogeneity in aerosol types using long data base.

• IONOSPHERE, MAGNETOSPHERE AND SOLAR TERRESTRIAL RELATIONSHIP

➢ Low-latitude Ionospheric response from GPS, IRI and TIE-GCM TEC to Solar cycle 24

This research is based upon the observed total electron content (TEC) from Global Positioning System (GPS), and modeled TEC from the International Reference Ionosphere (IRI-2016) model and Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIE-GCM) during solar cycle 24. The short and long term variability in TEC has been assessed by using spectral, regression and statistical analysis. To ascertain the quiet-time climatology, TEC data have been used after filtering out the solar flares and geomagnetic storms effects. Our analysis exhibits a double-hump structure (Figure 2) and clockwise hysteresis in TEC about the solar cycle-24. Solar flux and TEC trend found to be lubberly during rise and agile during fall of solar cycle-24. Seasonally, the semi-annual anomaly found to be a consistent feature with all phases of solar cycle while winter anomaly found to be facilitated with a level of solar activity during solstices. Another purpose of work is to investigate the performance of IRI-2016 and the TIE-GCM 2.0 models in comparison with GPS TEC during the solar cycle-24.

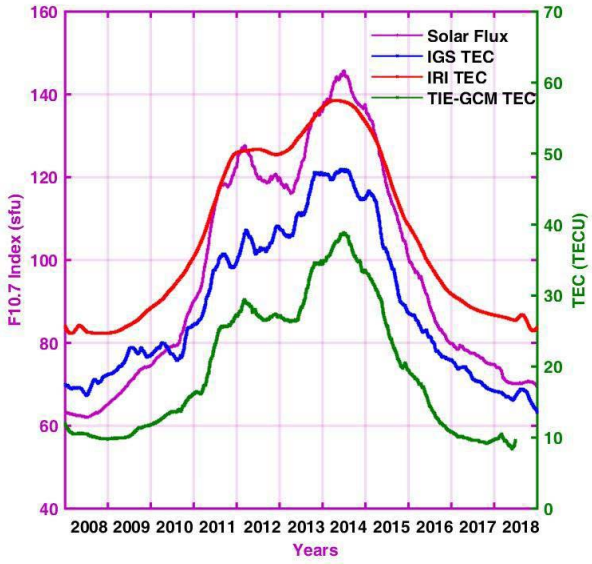

Fig 2: *Variation of 365 day centered-mean smoothed data of F10.7 cm index and TEC (GPS, IRI and TIE-GCM TEC) at northern low-latitude station Varanasi, India during Solar Cycle 24.*

➢ Occurrence characteristics of ionospheric irregularities over Indian low-latitude region Varanasi during ascending phase of solar cycle 24:

This study presents diurnal and seasonal variations of ionospheric irregularities during ascending phase of solar activity from 2009 to 2014 by using the amplitude scintillation index S_4 computed from a dual frequency GPS receiver installed at the low-latitude station of Varanasi (Lat. 25.3176° N, Long. 82.9739° E). Scintillation occurrences are found to be higher during night-time hours (19:30 - 01:30 LT) and characterized by an equinoctial maximum throughout the years 2009 - 2014, except for the peculiar solar minimum year 2009. Gravity wave seed perturbation from lower atmosphere and pre-reversal enhancement (PRE) in zonal electric field have been considered to explain the observed seasonal occurrences, which have been also compared with the previous results obtained from observations and model. Influence of solar activity on scintillation occurrence has also been studied, and it was found that there is linear dependence between the solar activity and scintillation occurrence, which is seasonally variable.

➢ Seismogenic ionospheric anomalies associated with the strong Indonesian earthquake occurred on 11 April 2012 (M= 8.5):

Ionospheric perturbations in possible association with a major earthquake (EQ) (M = 8.5) which occurred in India-Oceania region are investigated by monitoring subionospheric propagation of VLF signals transmitted from the NWC transmitter (F = 19.8 kHz), Australia to a receiving station at Varanasi (geographic lat. 25.3° N, long 82.99° E), India. The EQ occurred on 11 April 2012 at 08:38:35 h UT (magnitude ≈ 8.5, depth = 10 km, and lat. = 2.3°N, long. = 93.0°E). A significant increase of few days before the EQ has been observed by using the nighttime amplitude fluctuation method (fixed frequency transmitter signal). The analysis of total electron contents (TEC) derived from the global positioning system (GPS) at three different stations namely, Hyderabad (latitude 17.38 °N, longitude 78. 48 °E), Singapore (latitude 1.37 ° N, longitude 103.84 ° E) and Port Blair (latitude 11.62° N, longitude 92.72° E) due to this EQ has also been presented. Significant perturbation in TEC data (enhancements and depletion) is noted before and after the main shock of the EQ. The possible mechanisms behind these perturbations due to EQ have also been discussed.

• ASTRONOMY AND ASTROPHYSICS:

➢ Interstellar Dehydrogenated PAH anions: Vibrational Spectra:

Molecular Astrophysics (Astrochemistry) group has been involved in investigating the signatures of Polycyclic Aromatic Hydrocarbon (PAH) molecules in the interstellar space. The vibrational spectra of the family of PAHs gives rise to emission bands in the mid-infrared part of electromagnetic spectrum. These bands have been observed using infrared telescopes in a variety of interstellar environments. The ubiquity of these features has led to the fact that PAHs might be universally present in galaxies and might be holding up 10% to 15% of the carbon.

➢ Modelling 30 Doradus in the Large Magellanic Cloud:

The interstellar dust grains and their properties have been studied. The photometric data at specific bands (viz. 8 um, 12 um, 24 um, etc.) were used. The interstellar dust were modeled around regions in the Milky Way and neighboring galaxies like the LMC, SMC, etc.

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CHAPTER 21.2

BANGALORE UNIVERSITY

BENGALURU

The Department of Physics of Bangalore University, Bengaluru is actively involved both in teaching and research in the areas of Atmospheric and space science, and started planetary physics from 2019-20. The Department of physics is supported by the ISROs Space Science Promotion Scheme (ISRO-SSPS) towards strengthening of academic and research activities in atmospheric and space science since 2010. At present, a course on Atmospheric and Space Science is continued by offering few electives for students of post-graduate studies in Physics. The major papers are on atmospheric physics, space physics, meteorology, monsoon dynamics, remote sensing, orbital dynamics, planetary physics.

The major research activities of Atmospheric and Space Science Research Lab (ASSR Lab) in the Department of Physics covers a variety of themes such as atmospheric radioactivity, aerosols, electricity in the atmosphere, remote sensing, monsoon and its variability, boundary layer, sun earth relationship, TEC, lightning activities and theoretical simulations. Through an MOM-AO project from SPL, working on the project entitled “Observation and Modeling studies of the Atmospheric Composition of Mars (OMAC)”. The University has major facilities of Automatic Weather Station, Mini Boundary Layer Mast, and World Wide Lightning Location Network (WWLLN) from University of Washington, USA for continuous monitoring of lightning flashes around Bengaluru, India. Recently added with a lightning sensor from earth network to support the wide network in India. Major research activities carried out by Bangalore University during Jan 2018- June 2020 in the areas of space science are described below.

A. MAJOR RESEARCH

- **Remote sensing of Earth’s resources and environment**

Recent times have witnessed increasing impact of industrialization and urban growth on environment. In addition, the potential climate changes and possible adverse impacts on the economy and society at large are causing concern. In India, one of the major concerns is the variability of monsoon rainfall and effects on agriculture and water management. The various parameters associated with environment and climate change need to be monitored and analyzed. The effects of global warming on the Indian subcontinent vary from the submergence of low-lying islands, frequent flooding, coastal degradation and melting of glaciers in the Indian Himalayas. Indian satellites INSAT and IRS launched in early 1980s heralded the era of Space observations. The IRS satellites are providing observations of parameters such as land use/cover, forest, water bodies, crops etc. while INSAT provides quantitative products such as Cloud Motion Vectors (CMVs), Quantitative Precipitation Estimates (QPEs), Outgoing Long-wave Radiation

(OLR), Vertical Temperature Profiles (VTPRs), Sea Surface Temperature. The satellite data is operationally used for generating long term database on vegetation, soil condition, rainfall, groundwater etc.. Some of the unique studies are Biosphere Reserve Monitoring, Mapping of Glacial Lakes & Water Bodies in Himalayas, Biodiversity Mapping, Early Warning of Drought and Severe Weather Events. The paper presents details of the studies and salient results. Currently several operational meteorological satellites are providing global and regional observations. Six different types of satellite systems currently in use are - 1) Visible/Infrared/Water Vapour Imagers, 2) Infrared Sounders, 3) Microwave Imagers, 4) Microwave Sounders, 5) Scatterometers and 6) Radar Altimeters. Though the water vapour imaging capability is available only on the geostationary satellite, the visible and infrared imagers are available on geostationary as well as polar orbiting satellites. The last four are currently available only on polar orbiting systems.

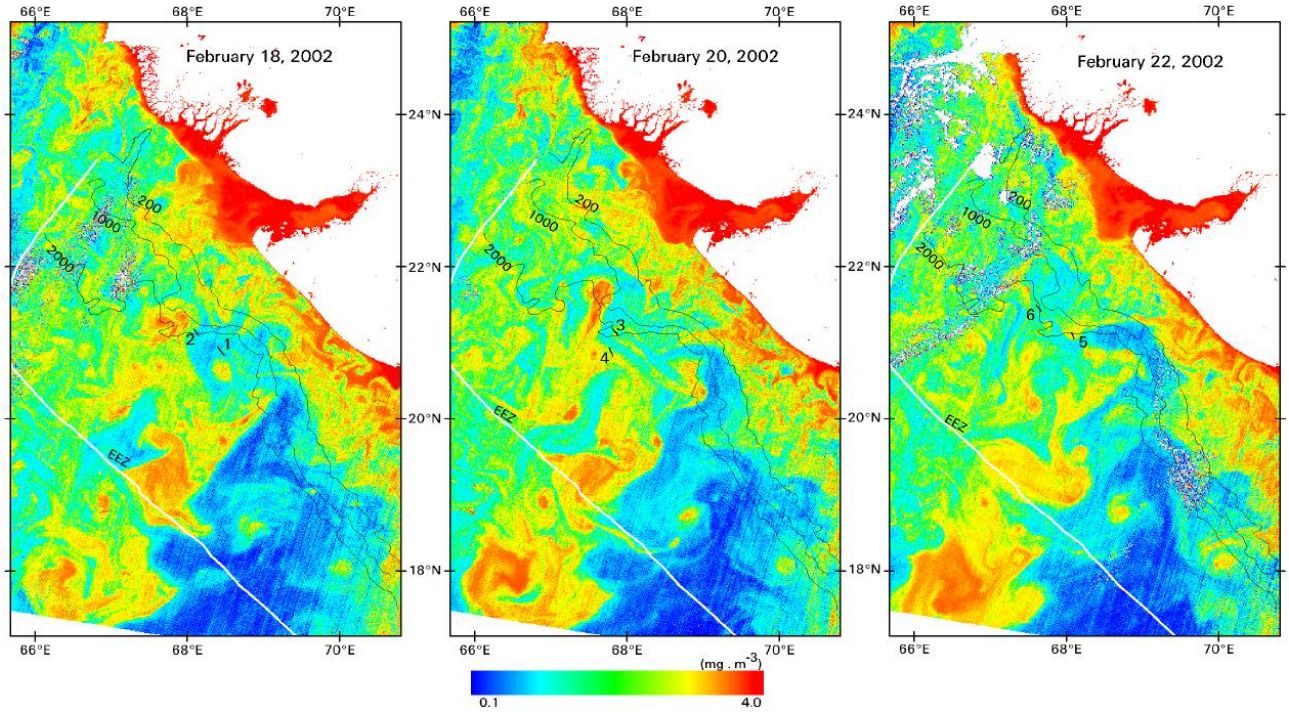

Fig. 1 Chlorophyll images generated from Oceanset I OCM data showing locations of fishing tracks

Fig 1: *Ocean productivity maps for Gulf of Kuchtch region, Gujarat*

Ocean productivity depends on key parameters such as ocean colour, chlorophyll concentration, mixed layer depth and sea surface temperature. The data from Ocean Colour Monitor of OCEANSAT 2 and Sea Surface Temperature from NOAA and INSAT are used to estimate ocean productivity. Figure-1 gives the productive regions in the ocean (Arabian Sea) and its temporal variation in a week's time. The climate change scenarios indicate large intake of CO_2 by oceans leading to increased productivity. IRS satellite observations have led a database of ocean productivity over Indian oceans for past two decades.

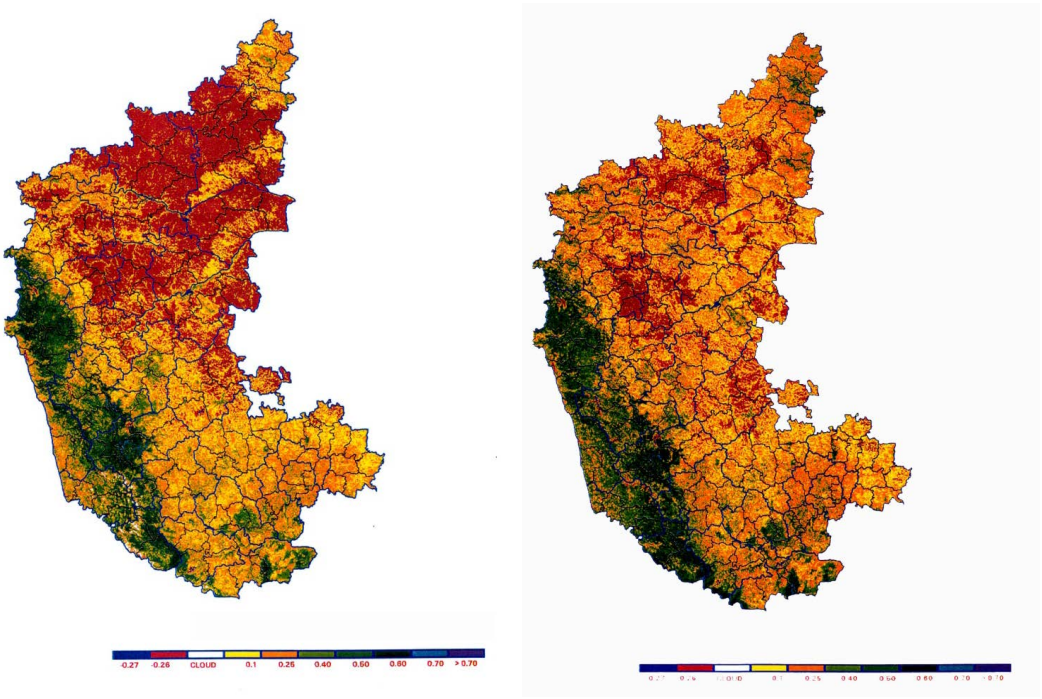

Fig 2: *Agricultural drought (red regions) in Karnataka for years 2000 and 2001*

The rainfall variability leads to decreased rainfall in certain regions of the country leading to aridity. Parts of Karnataka, Andhra Pradesh and Maharashtra have recurrent droughts. Study of the rainfall anomaly and extent and frequency of drought can help in locating highly vulnerable areas to climate change. The vegetation responds to rainfall and solar radiation and this is reflected in the satellite measurements as vegetation index (NDVI). The physical basis of this relation is vegetation, mainly grown due to soil moisture availability as the result of the seasonal rainfall, which intercepts photo-synthetically active radiation (PAR) and hence directly influences the aggregate of NDVI. Although there have been several studies reporting the relation between AVHRR NDVI and rainfall in semi-arid regions the sensitivity of this relation in varying dry land conditions has rarely been analyzed quantitatively. The present study aims to interpret seasonal AVHRR NDVI variations with the seasonal aggregate of rainfall and fraction of soil moisture used by vegetation in the six drought prone districts of Karnataka State, India representing very severe, severe and moderate drought conditions. Area averaged seasonal transpiration which has been theoretically linked to integrated NDVI (INDVI), has been realized up to a certain extent in the study areas. The variability in rainfall and its reflection in the vegetation cover is revealed in this study in dry land ecosystems. Fig 2 shows the variation in agricultural drought (red regions) in Karnataka for years 2000 and 2001 derived from satellite data.

- **Earth's atmosphere and climate**

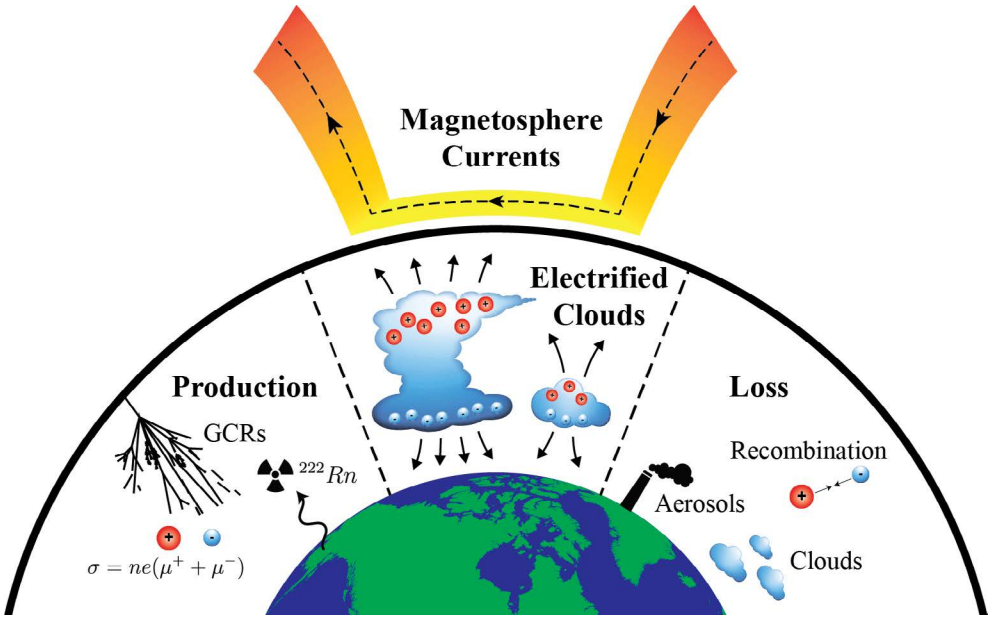

Fig 3: *Schematic representation of Global Electric Circuit*

The pictorial representation of the global electric circuit for different kinds of sources of ionization is shown in Fig 3**.** The variations in total air conductivity values for time and month number for 2014 and 2015 are shown in above Fig 4. Air diurnal variations are pronounced in January and February with early morning hour maximum and afternoon minimum. But, the conductivity values decrease as proceeds to March and April and ultimately relatively lower values are observed in July, August, and September, which falls in monsoon months.

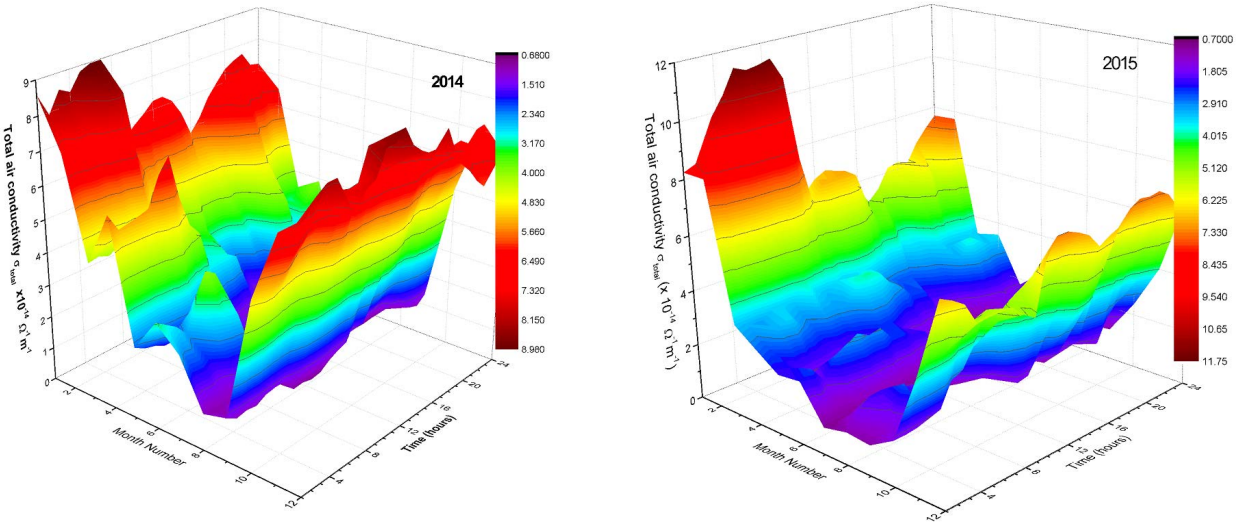

Fig 4: *Variations in air conductivity with time and month for 2014 and 2015*

- **The Solar system bodies including Planetary Science**

Mars Exospheric Neutral Composition Analyser of Mars Orbiter Mission provides insitu neutral atmospheric composition of Mars. The collision-dominant homosphere were sampled during low solar active conditions. Atmospheric composition measured in subsequent orbits in these region shows signatures of gravity waves considerably between 160-180 km, manifesting similar detections from NGIMS instrument aboard MAVEN. Exponential decay of out-gassing of volatiles upto two order of magnitude were observed by MOM, is primarily due to the long-term exposure of instruments and spacecraft under solar illumination conditions complimenting with the observational cadence. Significant variations in the atmospheric densities of major species were observed during each in- and out-bounds, as a result of varying temperature in the lower atmosphere of Mars. The high energy fluxes of solar wind particles dissociated carbon dioxide and produced considerable oxygen during June 2018 were observed over Mars. This is a new result that in absence of a global magnetic field of Mars, the direct interaction of solar wind charged particles affect the daily variation of thermosphere /exosphere gaseous concentrations. This also may contribute to the steady escape of atomic oxygen with enhanced solar activity.

From the ion currents differentiated with amu values, the partial pressures of atmospheric constituents can be estimated for obtaining the time/altitude profiles. Since the traverse time through the periareion is relatively short for the period of useful data collection within same orbit, the effect of change in solar zenith angle would likely be negligible. But for long term variability, the seasonal changes in solar zenith angles need to be corrected for studying any effect of solar activity related variations in exospheric partial pressures. The variation of atmospheric CO_2 density near the periareion region between 160 to 500 km by subtracting the background noise at 500 km. This covers the Martian upper thermosphere, its exobase and lower exosphere regions for ascertaining relative effects of gaseous transition and escape. It is also observed that the rate of change of pressure values for inbound and outbound trajectories are generally symmetric. Further analysis has been carried out to check the effect of Solar Zenith Angle (SZA) on the density variation of major atmospheric constituents with altitude. Fig 5 shows the results of these density profiles along with the variation of SZA. It can be seen that the SZA variation is from the night-side towards the evening-side and this transition does not affect the density profiles appreciably for the short duration of observations.

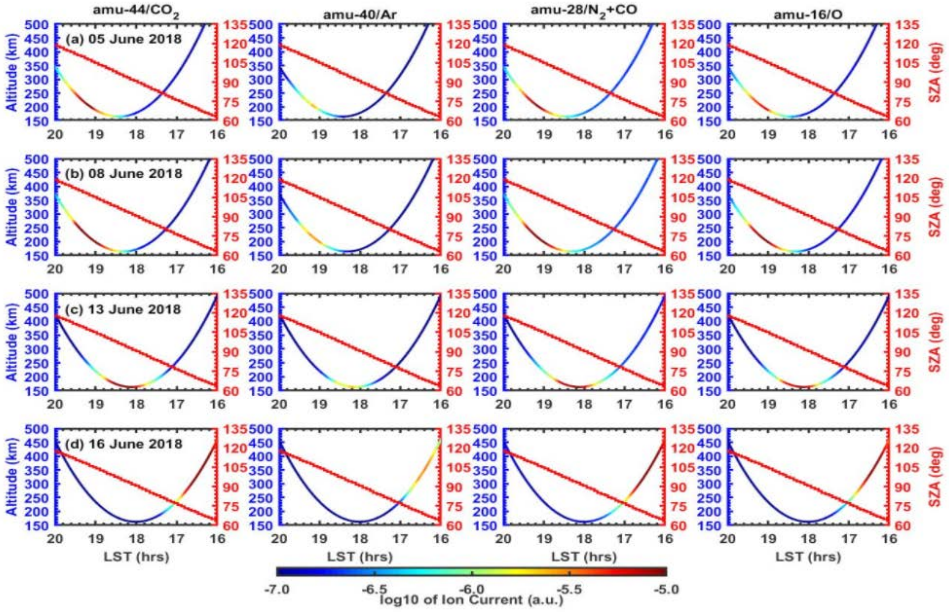

Fig 5: *Density profiles along with the variation of SZA*

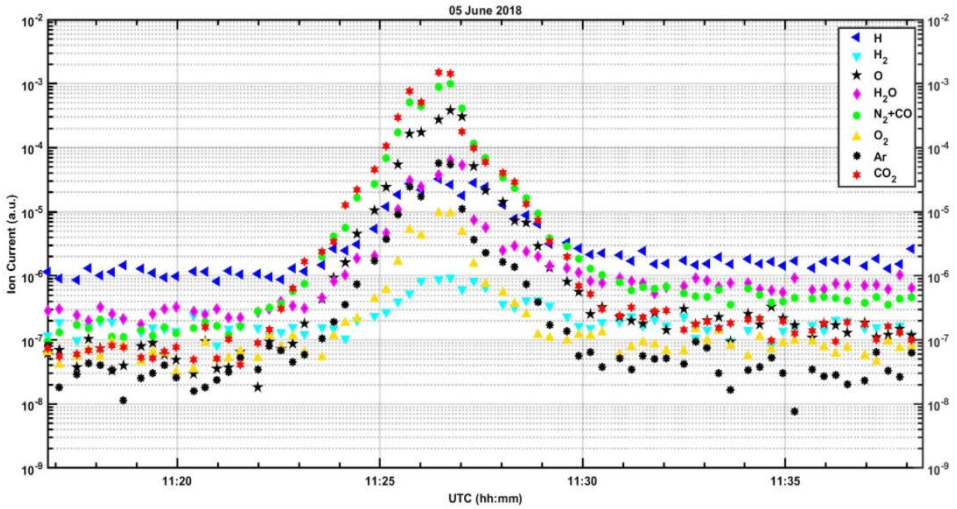

Fig 6: *Relative magnitude of major atmospheric constituents*

Fig 6 shows the relative magnitude of major atmospheric constituents by directly plotting the ion currents in arbitrary units. It is noted that the CO_2 shows the maximum density values and other constituents have generally lower pressures compared to CO_2 according to the known pattern of variation. Also it is to be noticed that the water vapour density (which is the product of outgassing in MOM) has reduced considerably compared to the values observed during 2014. However, the temporal profile of H_2O follows similar pattern of other species which points to the fact that further degassing may have stopped and the remnant water vapour while escaping is maintaining the hydrostatic equilibrium.

- **Balloon launch campaigns**

The department is supported by ISRO on Dr Pisharoty GPS – Radiosonde balloon launches for upper air observations. The daily twice launch of Pisharoty GPS-Radiosondes using helium filled latex rubber balloons. The launch campaigns were carried out at 00 and 12 GMT on each day for 10-days prior to satellite launch by ISRO. Obtained the upper atmospheric observations such as pressure, temperature, relative humidity, horizontal wind speed and wind direction, from near surface level to the level of balloon burst (~34km height) and sent the data to SDSC-SHAR as input to the model to know the wind characteristics. Almost 150 campaigns were performed during 2-years.

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CHAPTER 21.3

DIBRUGARH UNIVERSITY

ASSAM

The three-decade long tradition of Space Science research in Dibrugarh University has been sustained in right earnest by the faculties and scholars of the Department of Physics and Centre for Atmospheric Studies in the last couple of years. The faculties are actively involved in various domain of space science research. Category wise research in the duration of Jan 2018-June 2020 are provided below.

A. MAJOR FACILITIES/INSTRUMENTS DEVELOPED

- **The SAMEER-Dibrugarh University Ionosonde**

A digital ionosonde was designed and built indigenously by SAMEER, Mumbai in collaboration with Dibrugarh University. The design objectives were to obtain good SNR ratio to mitigate the heavy noise due to interference, obtain short duration ionograms, estimate vertical drifts, reconstruct vertical electron density profile, and make the antenna size smaller. The basic ionograms recorded by this system were compared with ionograms obtained from a co-located CADI Ionosonde, which is in operation in Dibrugarh since 2010. Ionospheric experiments conducted with the SAMEER-Dibrugarh University Ionsosonde produced promising results like the detection of travelling ionospheric disturbances, Es layer substructures, growth and decay of spread F etc. The system is in operation in the Dibrugarh University campus since 2018.

B. MAJOR RESEARCH

- **Earth's atmosphere and climate**

➢ **Vertical distribution of aerosols and clouds over North-East India**

South Asia, particularly India and the adjoining Sub-Himalayan region is home to variety of aerosols of both natural and anthropogenic origin that play a significant role in climate change. Increasing anthropogenic emission due to rapid industrialization and population density coupled with complex orography have contributed to substantial loading of anthropogenic and natural aerosols making the region conducive for ACI. The vertical distribution and the subtype of aerosols and clouds have been studied over the north-eastern South Asia (22–30°N, 88–98°E) for June 2006–May 2017 using CALIPSO and MODIS data.

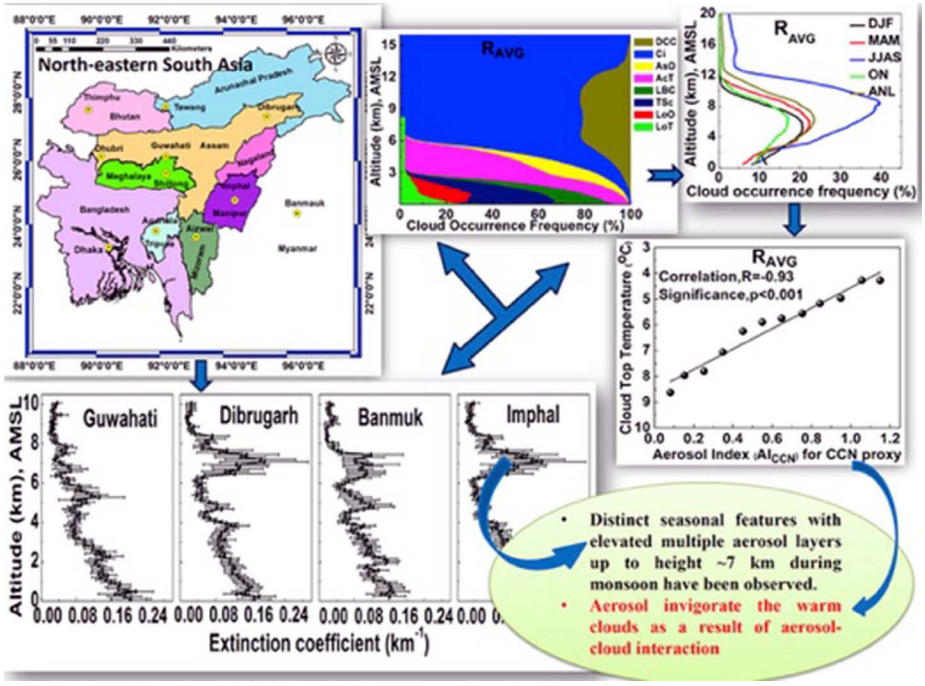

Fig.1 *Graphical abstract depicting the vertical distribution of aerosols and clouds as obtained from CALIPSO and MODIS over North East India for the period 2007-2016.*

➢ RegCM 4.4 aerosols and chemistry simulations over South Asia

The fourth generation ICTP regional climate model (RegCM4) has been used to simulate the aerosol optical depth (AOD), black carbon (BC) and aerosol direct radiative forcing (DRF) for the period 2011–2014 over Coordinated Regional Climate Downscaling Experiment (CORDEX), with special emphasis on North Eastern Region. Cumulus convective precipitation (CCP) scheme, planetary boundary layer (PBL) and land-surface scheme, were initially investigated for the period 1998–2002, by performing a series of sensitivity tests. The Tiedtke and University of Washington (UW) were considered as CCP and PBL schemes respectively and for the land-surface scheme community land model version 4.5 (CLM 4.5) was coupled with RegCM4 at 50 km resolution. The simulation with these parameterization schemes well captured the monsoon precipitation pattern over India ~ 7 mm/day and North Eastern Region of India (NER) ~ 12 mm/day, which are comparable to observations with a significant correlation of $R^2 > 0.93$.

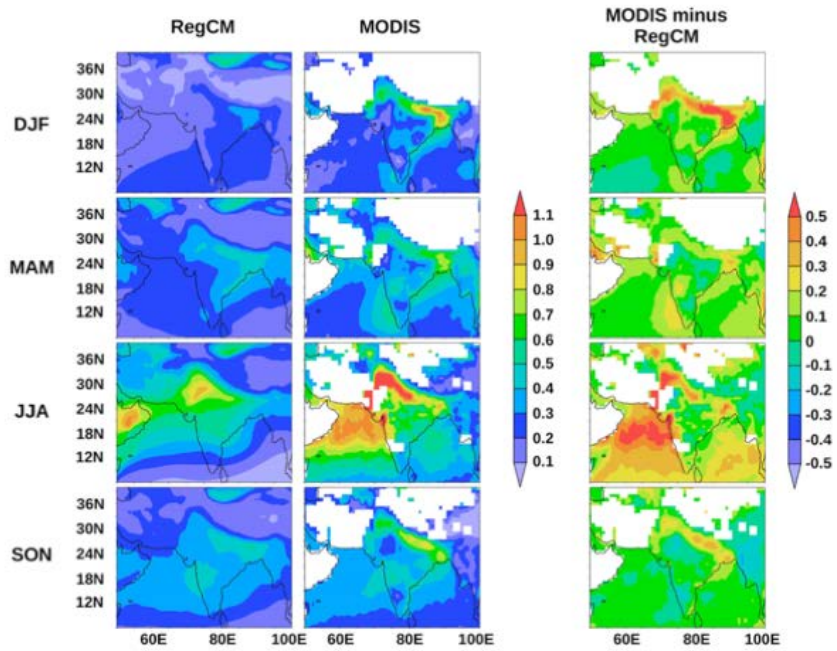

Fig.2 *Spatial distribution of seasonal AOD simulated by RegCM using Regional Emission inventory in Asia (REAS) emission inventories, MODIS observation and bias between MODIS and RegCM experiment.*

➢ Characterization of bioaerosols across Northeast India

Bioaerosols play an important role in spreading biological organisms and reproductive materials (pollens, spores, etc.). These are linked to many different diseases in human, animal and plant. Effort was made to analyze the biological components along with inhalable, thoracic and alveolic particles in aerosol samples collected from nine distinct locations of Northeast India during October-November. Microscopic analysis reveals the presence of 70-90% of non-biological particles followed respectively by pollens (9-18%), animal debris (1-12%) and fungal spores (1-6%). The concentration of bacteria in air sample ranges from 45.5 to 645.84 CFU/m^3 (colony formation unit per metre cube). The predominant microbial genera in the collected bioaerosol samples were identified as Gram positive Diplobacilli sp. followed by Diplococci sp. All the bacterial isolates showed sensitivity against broad (Chloramphenicol and Ampicilin) and narrow (Vancomycin and Erythromycin) spectrum antibiotics which indicates lesser threat to human health. Pollens of 10-20 µm diameter, which are mostly considered as potential allergens, contribute only up to 20% of total pollen content in the bioaerosol sample collected from various locations indicating healthier air.

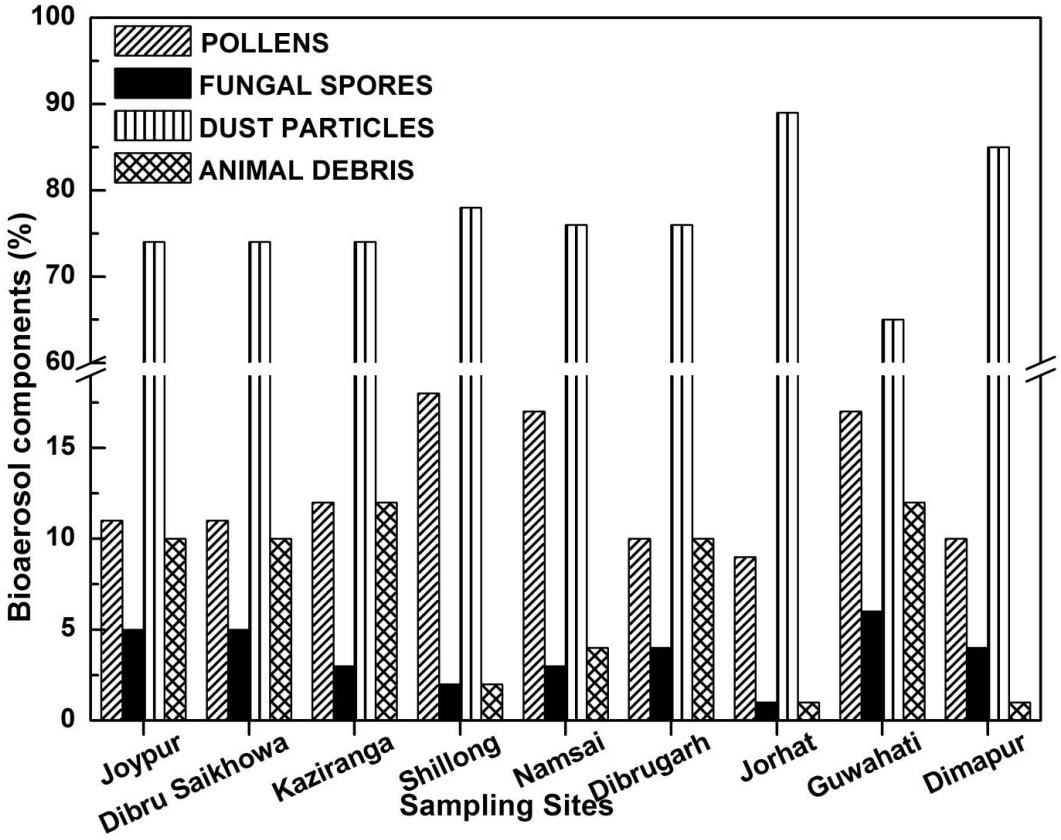

Fig.3: *Percentage Distribution of different bioaerosols components: Fungal spores, animal debris, pollens and non-biological component different sampling sites across NE India*

➢ Trends in global direct aerosol radiative forcing

Assessing global distribution of aerosol direct radiative forcing (DRF) and their long-term trends are vital to improve the state of understanding about the significance of aerosol climate forcing as well as the effectiveness of emission control policies. the global estimation of DRFs has always been challenging especially due to inhomogeneity in both land surface and aerosol properties, posing most uncertain component for the estimation of cumulative radiative forcing. Global distribution of aerosol direct radiative forcing (DRF) is estimated using Clouds and Earth's Radiant Energy System (CERES) synoptic (SYN) 1° datasets. From 2001 to 2017, statistically significant change of global DRFs is revealed with a general decreasing trend (i.e., a reduced cooling effect) at the top of the atmosphere (DRF TOA ~ 0.017 Wm^{-2} $year^{-1}$) and at the surface (DRF SFC ~ 0.033 Wm^{-2} $year^{-1}$) with rapid change over the land compared to the global ocean. South Asia and Africa/Middle East regions depict significant increasing trend of atmospheric warming by 0.025 and 0.002 $W.m^{-2}$ $year^{-1}$, whereas, the rest of the regions show a decline. These regional variations significantly modulate the global mean DRF (-5.36 ± 0.04 $W.m^{-2}$ at the TOA and -9.64 ± 0.07 $W.m^{-2}$ at the surface during the study period). The observed DRF trends are coincident with the change in the underlying aerosol properties.

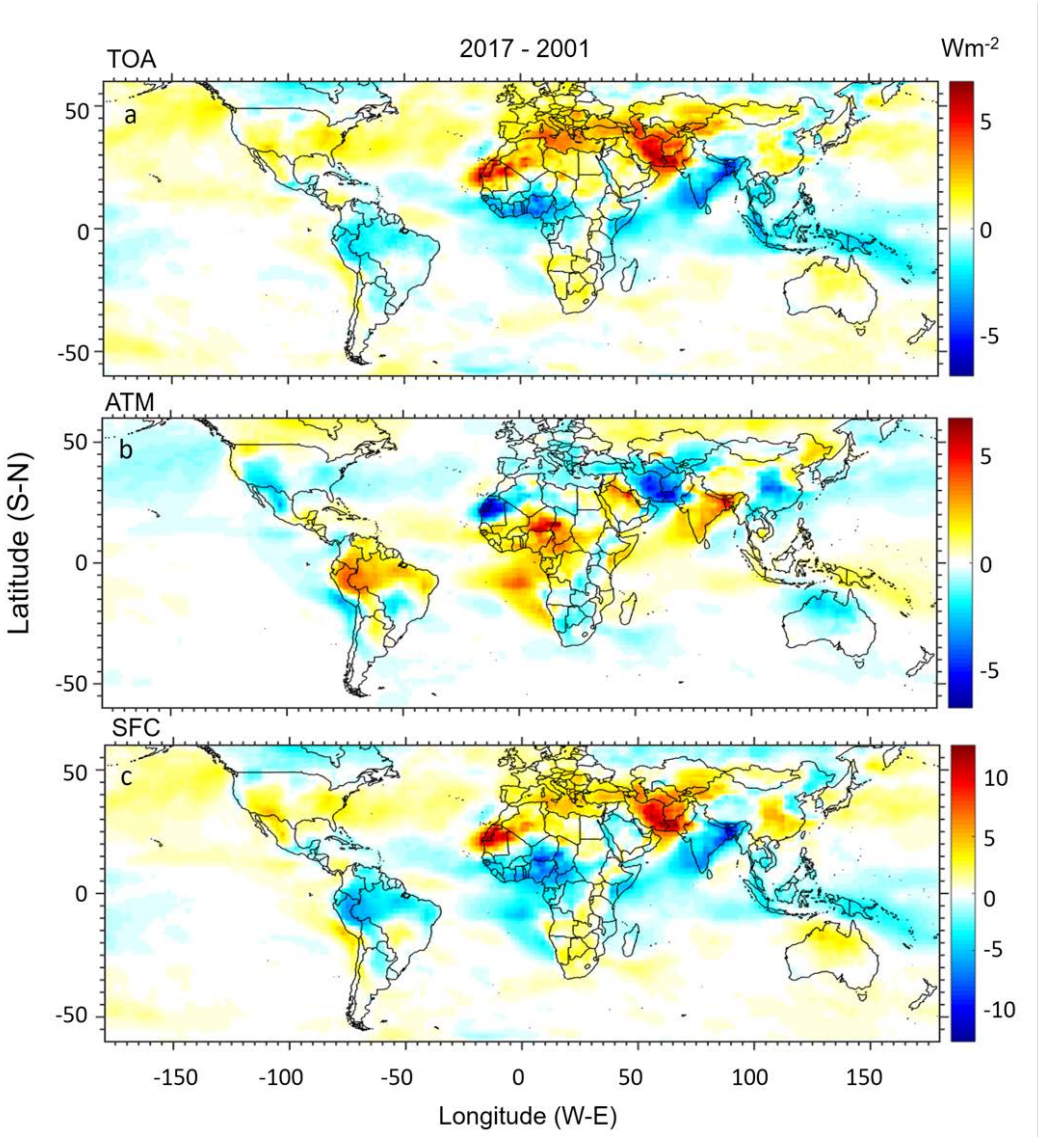

Fig. 4 *The difference in aerosol direct radiative forcing between 2017 and 2001 at the top of the atmosphere (a, TOA), in the atmosphere (b, ATM) and at the surface (c, SFC) as obtained from CERES synoptic (SYN) 1° datasets over the globe.*

- **Ionosphere, Magnetosphere and Solar Terrestrial relations**

➢ **Spatial extent of equinoctial L band scintillation around 95°E**

Nighttime L-band (1.575 GHz) scintillations occurred frequently during the ascending half of solar cycle 24 at the low midlatitude location, Dibrugarh (27.5°N, 95°E, 43°dip) with maximum occurrence in the equinoxes. Therefore, a study was undertaken to examine the extent of the equatorial scintillations as well as to investigate the occurrence characteristics and mechanism of off-equatorial (midlatitude) scintillations at L-band around 95°E during the equinoctial months from 2015 to 2016. The nature and extent of the irregularities causing L-band nighttime scintillations

at a group of five stations: Dibrugarh (27.5°N, 95°E, 43°dip), Kohima (25.6°N, 94.1°E, 39°dip), Aizawl (23.7°N, 92.8°E, 36°dip), Port Blair (11.6°N, 92.7°E, 9°dip), and Cocos Islands (12.2°S, 96.8°E, 43°dip) from the northern low midlatitudes to southern midlatitudes along 95°E meridian is investigated. GNSS/GPS/Ionosonde measurements were utilized. Dibrugarh and Cocos Islands are magnetically conjugate. Scintillations occur more frequently around the EIA crest where the background plasma density plays an important role. It is also observed that L-band scintillations around this sector decrease considerably from equinoctial months of 2015 to equinoctial months of 2016. The anomalous El Niño-Southern Oscillation and quasi-biennial oscillation recorded during the 2015–2016 winter might have contributed partly to the suppression of irregularities (and hence scintillations) in the succeeding equinox. Strong pre-midnight scintillations when triggered by equatorial spread F occur simultaneously at all stations. The zonal/vertical drift velocities of irregularities decrease from post-sunset to midnight hours. On the other hand, simultaneous sporadic E and post-midnight scintillations occur over Dibrugarh and Cocos Islands in the absence of scintillations at the equator, which are the manifestation of a frontal structure of sporadic E.

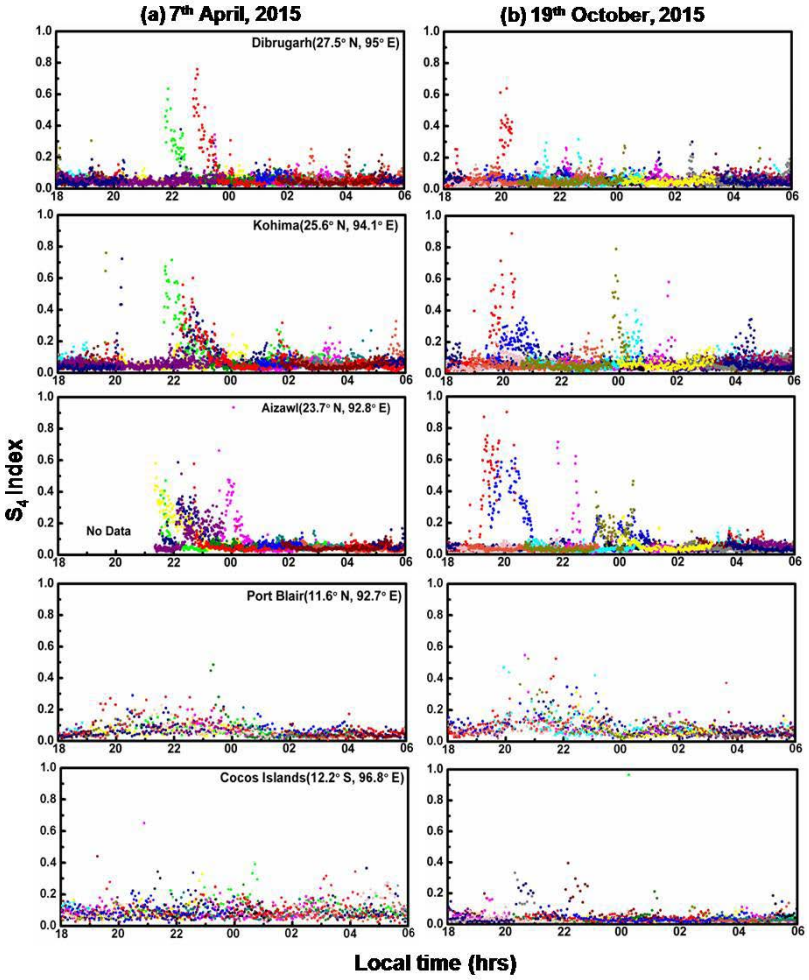

Fig.5 *Examples of simultaneous occurrence of 1.25 GHz scintillations along 95°E from northern low midlatitude (Dibrugarh) to southern midlatitude (Cocos Islands) on (a) 7 April and (b) 19 October 2015.*

➢ Longitudinal and inter-hemispheric asymmetry in topside ion density and vertical E x B plasma drift velocity within 75°E–95°E

The ion density measured by the ROCSAT -1 satellite from 1999-2003 over the 75°E and 95°E meridian at 600km altitude were utilized to examine the latitudinal and longitudinal distribution within the Indian sector, in particular, the north-south and east-west asymmetries of the equatorial ionization anomaly (EIA). The study conducted for the first time in this sector established that a longitudinal gradient in ion density at 600 km higher towards 95°E develops during the noontime and afternoon hours when the EIA is at its peak. The vertical ExB plasma drift velocity measured simultaneously by ROCSAT -1 exhibits the longitudinal gradient in addition to diurnal, seasonal and solar activity variations. The longitudinal asymmetry of drift velocity along 75°E and 95°E longitude sectors is the contributing factor behind the observed longitudinal asymmetry in ion density. The EIA at the altitude of 600 km peaks at different latitudes and are mostly asymmetric about the magnetic equator. The ion density across the equator is nearly uniform in the equinoxes while in the solstices, the density exhibits a north-south gradient. The strength of the EIA exhibits seasonal, year-to-year and hemispheric variations.

• Astronomy and Astrophysics

The faculty at Dibrugarh have investigated the higher dimensional cosmological dynamics in the framework of $f(R)$ gravity theory. The dynamics of a wide variety of $f(R)$ and Hu-Sawicki $f(R)$ model. All the works furnish the qualitative description of the cosmological dynamics of $f(R)$ gravity within the framework of a number of anisotropic Bianchi models such as Bianchi type I, Bianchi type III and Bianchi type V with a purpose to enrich with new information about the anisotropy parameters existing in the early universe and the late time cosmic acceleration. In the study, Born-Infeld theory combined with $f(R)$ gravity and explored the cosmological dynamics in the framework of isotropic Friedmann Lemaitre Robertson Walker (FLRW) model, anisotropic Bianchi type I and Bianchi type V models which can explain early as well as late time cosmic acceleration.

Over the past few years, Palatini formalism of f(R) gravity theory has gained sufficient interest from the perspective of the cosmological tests. The recent work is dedicated to the qualitative description of the cosmological dynamics of Palatini f(R) gravity within the framework of anisotropic Bianchi models with an intention to shed new insight to the anisotropy prevailing in the early universe and late time cosmic acceleration. Promising results that provide interesting information regarding the dynamics of early as well as late universe were arrived at.

Simulation studies on different aspects of Cherenkov photons have been carried out during the period of 2012–2018. The distribution patterns of lateral density, arrival time and angular position of Cherenkov photons in Extensive Air Showers (EASs) of gamma-ray, proton and iron primaries incident with various energies and at various zenith angles over a high-altitude observation level have been studied.

CHAPTER 21.3
DIBRUGARH UNIVERSITY

Studies on the nature of Gravitational Waves (GWs) in modified theory of gravity are being pursued and a study on the different polarization modes of GWs in f(R) gravity power law model in de Sitter space had been carried out. A new f(R) gravity model has been proposed to study the polarization modes of GWs as well as to deal with the existing problems and also to explore new directions in physics of gravity, as an attempt to have a model with more parametric control. In the area of SO, anharmonic vibrational behaviour of pulsating stars are being studied to understand the underlying physics behind the nature of such stars. The DE scalar field models and the modified gravity models intend to explain the late time cosmic acceleration from the perspective of the missing energy content and the large-scale spacetime behaviour of the Universe respectively. The formation of caustics in the Dirac-Born-Infeld (DBI) type scalar field systems had also been studied and this study has facilitated the rejection of some of the unphysical DBI scalar field models. The features of the scalar degrees of freedom and the consequent cosmological implications of power-law and the Starobinsky f(R) gravity models in Einstein frame constitutes an important area of study. The f(R) gravity models belong to an important class of modified gravity models and these models can be expressed in terms of a scalar degree of freedom by redefining of model's variable. The scalar degree of freedom becomes more explicit and can be studied conveniently under the conformal transformation of the action from Jordan frame to Einstein frame. Work on modified gravity, especially on the f(R) gravity models to explain the mystery of DE is in progress.

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CHAPTER 21.4

INSTITUTE OF RADIO PHYSICS AND ELECTRONICS UNIVERSITY OF CALCUTTA

Kolkata

The Institute of Radio Physics and Electronics, established in 1949 as a post-graduate teaching and research department of the University of Calcutta, has a rich tradition of radio and space research pioneered by Late Professor Sisir Kumar Mitra, FRS. This institute provides a platform for multifaceted research activities in space, atmospheric and radio sciences in the University. A brief description of the work carried out during 2018-2020 at the Institute is provided this report.

The Institute of Radio Physics and Electronics has been engaged in space and atmospheric science research covering lower and upper atmosphere. The operational experimental systems include radars, satellite signal receiving systems, optical and microwave radiometers, aerosol measurement instruments, electric field measurements, disdrometers, GNSS receivers, IRNSS receiver, GNU VHF receiver, and meteorological instruments. A ST Radar facility at 53 MHz is upcoming at the Haringhata Field Station of the University of Calcutta. The studies of lower atmosphere during 2018-2020 are mainly focussed on the atmospheric processes that include convective events and associated gravity waves, boundary layer dynamics, aerosols and their effects on atmospheric electric field, convection induced aliasing effects in radar Doppler spectra, rain-induced satellite signal propagation effects, radiometric studies for rainfall prediction and rain classification. The investigations have characterized the atmospheric features at an urban tropical location situated near land-sea boundary that experiences both convective features of land surface and weather fronts from Bay of Bengal.

The other area in which a major effort has been given is the ionosphere and space weather studies. The investigations in this area have dealt with the electron content near the northern anomaly crest using GPS and IRNSS signals. The ionospheric irregularity structures have been investigated during the solar minimum period. The performances of different navigational satellite systems have been studied under adverse ionospheric conditions. The long term aspects of night time spread F over a mid latitude station has also been investigated during this period.

A. MAJOR FACILITIES/INSTRUMENTATION DEVELOPED

➢ ST Radar Facility at the University of Calcutta

A major facility of Stratosphere Troposphere (ST) Radar, funded by SERB, DST, is coming up at the Haringhata Field Station of the University of Calcutta to carry out scientific studies on stratosphere-troposphere exchange process, gravity waves, equatorial/planetary waves and ionospheric E and F region irregularities over Kolkata located at the verge of the tropics. The

data products from the radar will be three component wind, Doppler spectral width and signal strength in the lower atmosphere and irregularity drift velocity and backscatter signal strength of ionospheric irregularities. Each antenna element in the array of 475 antennas will be fed by a separate transmitter with 2 kW power so that the radar will have flexible antenna beam steering capability. The radar is configured into 25 sub-arrays each having 19 transmitter receiver modules. The frequency of operation of the radar is around 53 MHz with an average power aperture product of 10^8 Wm^2. The proposed radar will probe the lower atmosphere from about 3-20 km and also ionospheric E and F region irregularities. A pilot version of the main radar has been operational since April 2018.

B. CATEGORY WISE SPACE RESEARCH ACTIVITIES AND MAJOR RESULTS

- **ATMOSPHERE AND CLIMATE**

➢ **Gravity Wave Behavior in Lower Stratosphere During Tropical Cyclones Over the Bay of Bengal**

Gravity waves associated with tropical cyclones over the Bay of Bengal have been studied using COSMIC GPS radio occultation measurements. The sources of gravity waves are located well below the tropopause where the intensity of a tropical cyclone (TC) is high. The gravity wave potential energy between 19 to 26 km height shows an enhancement in the lower stratosphere (LS) during the cyclone. Intense convection associated with TC is characterized by low outgoing long wave radiation (OLR) values. An increase in potential energy in the lower stratosphere occurs over a storm path before the actual occurrence of cyclones. The power spectral density of gravity waves shows that the vertical wavelengths in the range 2-2.4 km carry the maximum energy in the LS over the cyclone path. Cyclone Sidr was one of the most intense cyclones on record to make its landfall over Bangladesh. This cyclone, originated in the centre of Bay of Bengal on 9 November 2007, arrived at the south-western coast of Bangladesh on 15 November 2007. The path followed by Sidr is depicted in Figure 1(a) by filled circles superimposed on the outgoing long wave radiation plot during the cyclone period (11-16 November 2007). It can be seen that the cyclone affected region is characterised by low OLR value (less than 180 W/m^2) indicating deep convection in the region. The average potential energy of gravity waves in the lower stratosphere (19-26 km) is calculated before (3-10 November 2007), during (11-16 November 2007) and after (22-29 November 2007) the cyclone using COSMIC RO temperature data. It is observed from the contour plot of potential energy that there is an increase in gravity wave potential energy(E_p) (1.94 J/kg)along the storm track before the cyclone (Figure 1 (b)) which spread over the adjoining region during the cyclone period (Figure 1(c)) with average E_p of 2.34 J/kg. Figure 1(d) shows that the energy dissipated after the cyclone is over.

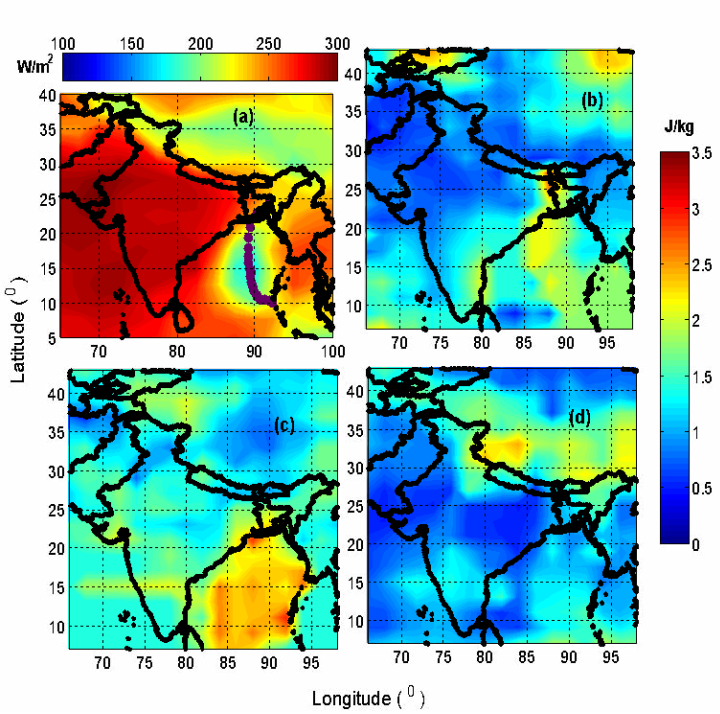

Fig. 1: *(a) Path of the cyclone Sidr, depicted by filled circles superimposed on the contour plot of average OLR (W/m^2) value during 11-16 November 2007. Contour plots of average potential energy (J/kg) in the height range 19-26 km, (b) before the cyclone (3-10 November), (c) during the cyclone (11-16 November), and (d) after the cyclone Sidr (22-29 November 2007).*

➢ Gravity Wave Activities Associated with Convective Phenomena at a Tropical Location near Land Sea Boundary

The seasonal analysis of gravity wave activity has been made for the present tropical location, Kolkata (22.5726° N, 88.3639° E) using radiosonde and ECMWF 60 model level data. Gravity waves generated due to intense tropical cyclone Aila have also been investigated using ECMWF 91 model level data over the Indian region. The gravity wave energy calculated from temperature and wind perturbation profiles show a significant enhancement during convective activities as indicated by a low outgoing long wave radiation. The pattern of zonal and meridional wind shears plays an important role in determining the seasonal variation of gravity wave activities. An intrusion of water vapour into the lower stratosphere over the cyclone affected region is detected from ECMWF 91 model level data. The dominant vertical wavelengths of gravity waves in the range of 2.5-3.2 km are found from spectral analysis of wind and temperature perturbations during the tropical cyclone.

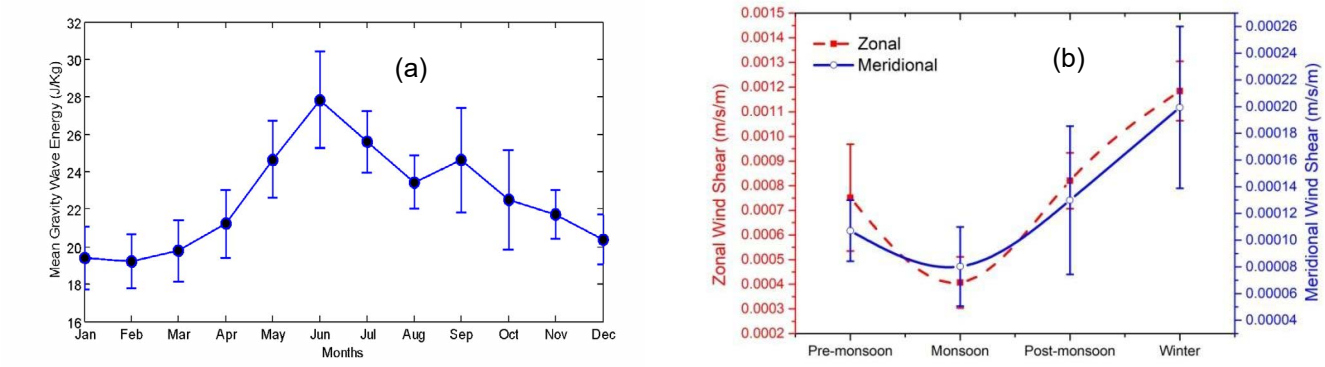

Fig. 2: *(a) Average gravity wave energy in the height range 18-25 km over Kolkata, and (b) Average zonal and meridional wind shear in LS over Kolkata for different months of 2010-2016.*

➢ Effect of Boundary Layer Dynamics on the Profiles of Rain Drop Size Distribution During Convective Rain

The profiles of rain microstructures have been investigated for different types of precipitation using Micro Rain Radar (MRR) observations at a tropical location Kolkata (22.57° N, 88.37° E). A prominent dip in radar reflectivity (Z) profile has been observed near the boundary layer at high rain rates. This phenomenon is due to the break-up of raindrops into smaller sizes at around 2 km height during intense convective events which results in the increase of drop concentration around 2 km

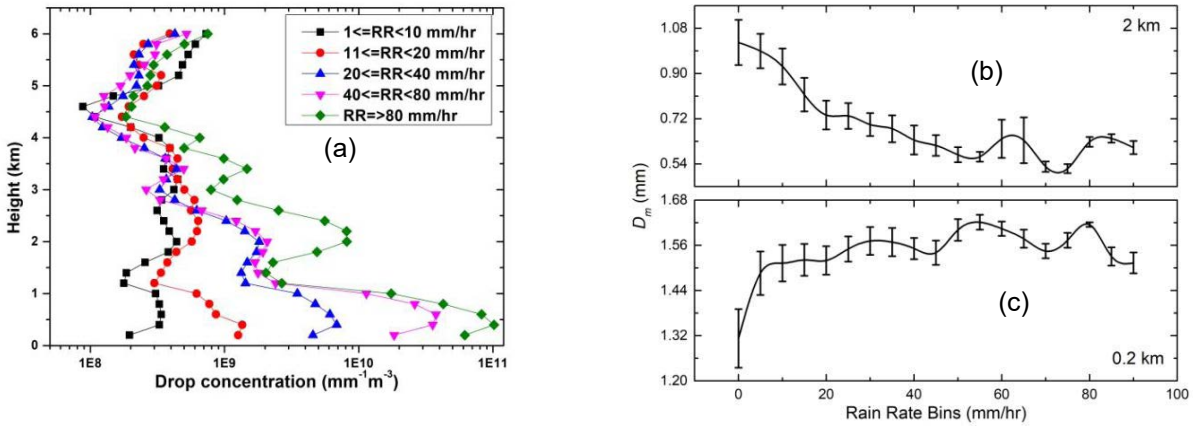

Fig. 3: *(a) Total rain drop concentration profile, and mass-weighted mean drop diameter (D_m) for different rain rate classes at (b) 2 km, and (c) 0.2 km.*

➢ Electric Field Variation in Clear and Convective Conditions at a Tropical Urban Location

The behaviour of the atmospheric electric field in terms of potential gradient (PG) has been studied during the period of 2013 and 2014 at a tropical and urban location Kolkata (22° 34'N, 88°22'E), India. The clear weather PG is influenced by varying concentrations of black carbon (BC) which is

a major pollutant in the urban atmosphere. The diurnal variation of the clear day PG follows that of the BC concentration in all the seasons. It is found that cloud base height (CBH) and liquid water path (LWP) correlate well with the PG change in convective events. It is shown that during a convective event the PG change measured over a 10 min interval about 30 min before the onset of rain can approximate impending rain accumulation.

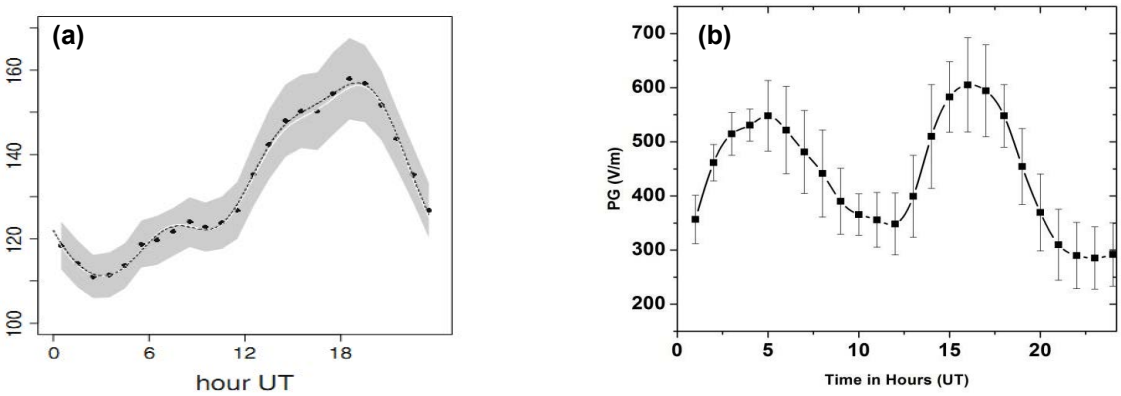

Fig. 4: *Comparison between (a) Carnegie curve calculated from the selected 82 undisturbed days of Cruise VII (after Harrison, 2013) and (b) PG observed at Kolkata on clear days in all seasons.*

➢ Aliasing Effect due to Convective Rain in Doppler Spectrum Observed by Micro Rain Radar at a Tropical Location

The spectral reflectivity in terms of Doppler velocity obtained by Micro Rain Radar (MRR) at a tropical location can reveal the splitting of Doppler spectrum of falling rain drops caused by strong downdraft. The phenomenon, known as aliasing, occurs in the Doppler spectrum of MRR during intense convective events if the rain drop velocity exceeds the unambiguous Doppler velocity range that can be sensed by MRR. The importance of the present study lies in the fact that the split in the Doppler spectrum can be utilized to estimate downdraft velocity during rain. The de-aliasing technique has been applied to the raw Doppler spectrum of MRR to retrieve the rain drop size distribution conforming to ground based measurements. The aliasing effect can be seen in the Doppler spectrum at the heights 1400 m during the time period 12:15-12:21 IST over Kolkata, India during a convective rain when there are discontinuities in the Doppler spectrum as shown in Figure 5(a). The rain rate and downdraft velocity are averaged for every 30 sec for the convective rain as depicted in Figure 5(b).

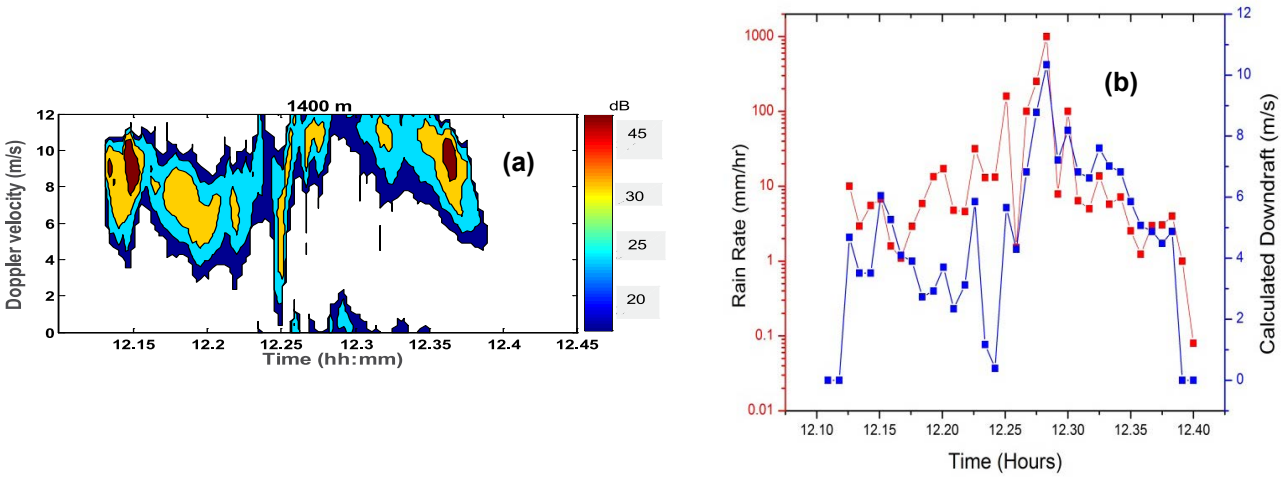

Fig.5: *The Doppler spectrum at (a) 1400m altitude, and (b) variation of rain rate (red curve) with downdraft velocity (blue curve) obtained during the convective rain event on 8 September 2014. The colour bar shows the spectral reflectivity in dB.*

➢ Multitechnique Rain Classification From Ground-Based Measurements Over a Tropical Location

The study aims to classify precipitations into two categories, namely stratiform and convective. Multiple techniques, utilizing Micro Rain Radar (MRR), Electric Field Monitor (EFM), Radiometer and Disdrometer measurements have been deployed for this purpose, at a tropical location Kolkata, India.

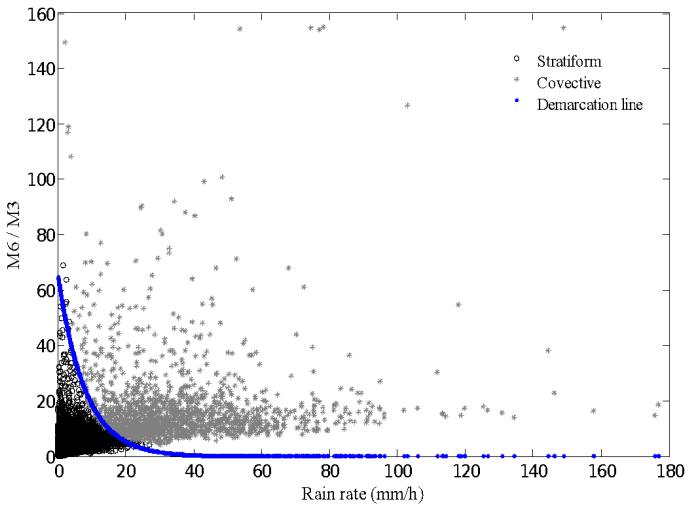

Fig.6: *Rain rate versus DSD moment ratio (M6/M3) for the year 2011.*

A new rain classification technique utilizing Disdrometer data and based on the Logistic Regression modelling of the sixth to third moment ratio *(M6/M3)* of drop size distributions has

been proposed. Figure 6 shows the decision boundary (blue demarcation line obtained by fitting a Logistic Regression model to the data), which effectively distinguishes between convective and stratiform precipitations. The observations on the bright band structure by MRR and on differential brightness temperature at 31.4 and 22.23 GHz by a radiometer are utilized to classify mixed rain types. EFM measurements give a distinct signature of the impending stratiform/convective rain events. A comparative analysis shows significant dominance of stratiform rain over convective rain. The convective phenomenon shows higher occurrences during the pre-monsoon period compared to the monsoon period at the present location.

➢ Prediction of Rain Occurrence and Accumulation Using Multifrequency Radiometric Observation

A nowcasting technique has been proposed to estimate the impending rain accumulation using ground-based radiometric measurements at Kolkata (22.65°N, 88.45°E), a tropical location in India. It has been observed that the normalized variation of brightness temperature (BT) at 31 GHz along with the standard deviation of BT at 22 GHz and instability indices, namely, lifting index, have shown definite changes before rain events. A combination of these three parameters can be effective in predicting rain events both qualitatively and quantitatively. Accordingly, a prediction model is developed and tested on several intense rain events during the period 2014–2015. The model performs reasonably well in predicting intense rain about 70–75 min in advance with an efficiency of 80%.

➢ Rain and Rain-induced Degradations of Satellite Links over a Tropical Location

Rain-induced propagation characteristics have been studied over a tropical location, Kolkata, using seven years of propagation data collected during 2004-2010. The location experiences substantial rainfall during Indian Summer Monsoon (ISM) which is preceded by pre-monsoon rainfall accompanied by strong convection. Accumulations, event duration and fade duration statistics are presented. Long-term observations for three propagation effects namely, rain attenuation, scintillations and depolarization are analyzed in this study. The seasonal patterns of these phenomena are examined to reveal the characteristic features of the present tropical location. The interrelations among rain rate, rain attenuation, scintillations and depolarization are investigated. For identical rain rates, the propagation detriments are more severe in pre-monsoon compared to monsoon period, mainly because of different microphysical properties of precipitation. However, the percentage occurrences of various propagation effects are much higher in monsoon than in pre-monsoon. Figure 7 shows the statistics of rain attenuation and XPD degradation over Kolkata.

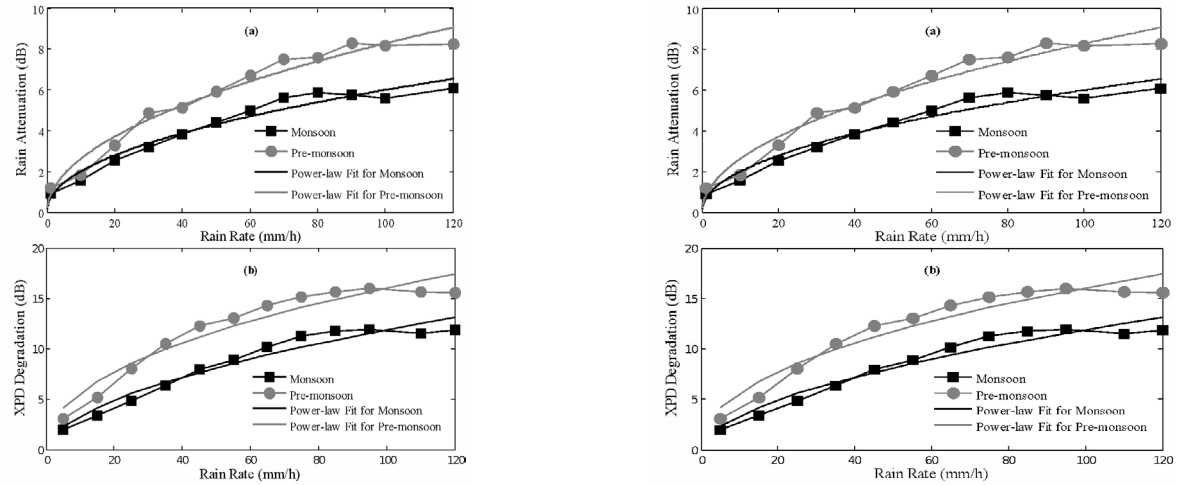

Fig. 7: *(a) Rain attenuation exceedance probability during the monsoon and pre-monsoon seasons along with ITU-R predicted and experimentally obtained worst month values, (b) comparison of annual rain attenuation exceedance with ITU-R predicted values, (c) variations of rain attenuation, and (d) XPD degradation with respect to rain rate.*

• IONOSPHERE, MAGNETOSPHERE AND SOLAR-TERRESTRIAL RELATIONSHIP

➢ Characteristics of electron content between GPS and IRNSS altitudes studied around the northern anomaly crest location over Indian longitude sector

One of the newly launched satellite navigation systems is the Indian Regional Navigation Satellite System (IRNSS) operating at L5 and S band and providing position determination with an accuracy of 10m over the Indian subcontinent and 1500km beyond. Collocation of this constellation, containing 3 geostationary and 4 geosynchronous satellites, with GPS over a common ionospheric volume at certain times of the day provide a unique opportunity to estimate the highly sparse electron content existing between the GPS and geostationary/synchronous orbital altitudes. These values of electron contents, though an order of magnitude less than the diurnal maximum of TEC, could account for a significant proportion of post-midnight TEC around the northern crest of Equatorial Ionization Anomaly (EIA) in the Indian longitude sector. Data recorded using a tri-band IRNSS receiver and dual-frequency GPS receiver from Calcutta during April-June 2019 have been analyzed to calculate electron contents along a specific look angle containing GPS as well as IRNSS satellite at different times of the day. Diurnal maximum values of 4-5 TECU are noted for electron contents bound within the altitudes of GPS and IRNSS. Spatial distribution of such electron content shows diurnal maximum around 14:00-15:00 LT over sub ionospheric swaths of 20°–22°N with 80°–82.5°E and 87°–90°E.

➢ Multi-wavelength coordinated observations of ionospheric irregularity structures from an anomaly crest location during unusual solar minimum of the 24th cycle

The present study reports coordinated ionospheric irregularity measurements at optical as well

as GPS wavelengths. Optical measurements were obtained from Tiny Ionospheric Photometer (TIP) sensors installed onboard the Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) satellites. GPS radio signals were obtained from a dual frequency GPS receiver operational at Calcutta (22.58°N, 88.38°E geographic; geomagnetic dip: 32.96°; 13.00°N, 161.63°E geomagnetic) under the SCIntillation Network Decision Aid (SCINDA) program. The observations were conducted during the unusually low and prolonged solar minima period of 2008-2010. During this period, four cases of post-sunset GPS scintillation were observed from Calcutta. Among those cases, simultaneous fluctuations in GPS Carrier-to-Noise ratios (C/N_o) and measured radiances from TIP over a common ionospheric volume were observed only on February 2, 2008 and September 25, 2008. Fluctuations observed in measured radiances (maximum 0.95 Rayleigh) from TIP due to ionospheric irregularities were found to correspond well with C/N_0 fluctuations on the GPS links observed from Calcutta. These measurements indicate the existence of electron density irregularities of scale sizes varying over several decades from 135.6 nm to 300–400 m beyond the northern crest of the EIA in the Indian longitude sector during late evening hours even in the unusually low solar activity conditions.

➢ Long-term aspects of nighttime spread F over a low mid-latitude European station

In an effort to explore the morphology of night time spread F at the lower mid-latitude European station of Nicosia, Cyprus (35°N, 33°E geographic; magnetic dip. 29.38°N), all ionograms recorded by the DPS-4D digisonde during the interval 2009–2016 have been analyzed. Subsequent detailed investigation was performed to establish the possible effect of various triggering mechanisms on spread F within the framework of Perkins instability on a statistical basis by correlating spread F occurrence particular wave pattern signatures (Satellite Trace/Multiple-reflected Echoes), gravity wave signatures, F layer uplift (h'F) and unstable sporadic E layers. The results verify the systemic manifestation and therefore the significance of TIDs and unstable sporadic E layers as triggering factors responsible for seeding spread F development and underline the frequent appearance of multi-reflected echoes and satellite traces as dominant precursors of mid-latitude spread F over European latitudes for the first time. Furthermore clear seasonal characteristics and inverse solar activity dependence of spread F occurrence in lower European mid-latitudes is established similar to southern hemisphere studies undertaken previously.

➢ Study of Relative Performance of Different Navigational Satellite Constellations Under Adverse Ionospheric Conditions

Detrimental effects of satellite signal outages during periods of intense equatorial ionospheric scintillations could be mitigated using multi-constellation satellites if provisions for interoperability of these satellite signals exist. In view of the sharp spatial gradient of ionization occurring in the equatorial region, comparison of satellite signal fluctuations from different constellations should be performed over limited spatial volume. This could be effective for maintaining and improving the performance of satellite-based communication and navigation without compromising the accuracy and integrity. A study presents a comparative assessment of the robustness of

GPS, GLONASS, and GALILEO satellites over a common ionospheric volume during periods of ionospheric scintillations for the equinoctial months of 2014 and March 2016 from Calcutta (22.58°N 88.38°E geographic; 32°N magnetic dip) and for September 2016 from Siliguri (26.72°N, 88.39°E; 39.49°N magnetic dip), located near the northern crest of equatorial ionization anomaly in the Indian longitude sector. It is found that for all the cases, carrier-to-noise ratio fluctuations over limited ionospheric volume from satellites of different constellations are comparable, thereby rendering them interoperable.

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Corner Reflector deployed at icesheet near Maitri Station, Antarctica on January 11, 2020 by 39th Indian Scientific Expedition to Antarctica (ISEA) Maitri team from Space Applications Centre, ISRO and National Centre for Polar and Ocean Research (NCPOR)